
ERGONOMÍA OCUPACIONAL
INVESTIGACIONES Y APLICACIONES

VOL. 19

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Datos de catalogación bibliográfica	
ENRIQUE DE LA VEGA BUSTILLOS, KARLA PATRICIA LUCERO DUARTE, CARLOS ESPEJO GUASCO, ELISA CHACÓN MARTÍNEZ, CARLOS RAUL NAVARRO.	
ERGONOMÍA OCUPACIONAL, INVESTIGACIONES Y SOLUCIONES VOL. 19	
Sociedad de Ergonomistas de México, A.C. (SEMAC) 2025	
ISBN: 979-8-218-93209-1	
Formato: Carta	Paginas 874

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Primera edición en español, 2026

ISBN: 979-8-218-93209-1

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Editado en México

SOCIEDAD DE ERGONOMISTAS DE MÉXICO A.C. (SEMAC)

2026

ERGONOMÍA OCUPACIONAL

INVESTIGACIONES Y SOLUCIONES

VOL. 19

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ENRIQUE DE LA VEGA BUSTILLOS
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Prefacio

Detrás de cada estadística de productividad y de cada protocolo normativo, existe una realidad innegable: el cuerpo humano. La ergonomía ocupacional, más allá de ser una disciplina técnica, es en esencia un acto de cuidado. En esta nueva edición de **"ERGONOMÍA OCUPACIONAL, INVESTIGACIONES Y SOLUCIONES"**, nos detenemos a reflexionar sobre el impacto profundo que nuestro campo tiene en la vida diaria de miles de trabajadores en México y Latinoamérica.

México atraviesa un momento vital. La implementación de la **NOM-036 STPS** no es solo un avance legislativo; es un reconocimiento a la dignidad del trabajador. Es una respuesta a quienes, jornada tras jornada, ponen su fuerza física al servicio del progreso. Los trabajos aquí reunidos sobre riesgos por movimientos repetitivos y manejo de cargas no hablan solo de ángulos de flexión o Newtons de fuerza; hablan de preservar la salud de manos que crean, de espaldas que sostienen familias y de cuerpos que merecen llegar al final del día con vitalidad, no con agotamiento.

En este volumen, la **Inteligencia Artificial** deja de ser un concepto abstracto para convertirse en una aliada de la empatía. Al integrar la IA en la ergonomía física, estamos logrando algo profundamente humano: entender mejor el cansancio antes de que se convierta en lesión. La tecnología nos permite hoy "escuchar" al cuerpo con una precisión que antes era imposible, transformando datos algorítmicos en soluciones que alivian la carga real de un operario en una línea de ensamble o de un agricultor en el campo.

Las investigaciones que conforman esta obra demuestran que la verdadera innovación en Latinoamérica no está solo en las máquinas, sino en la mirada sensible del investigador. Encontrarán aquí soluciones que nacen de la observación directa y del respeto por la diversidad física y cultural de nuestra región. Porque una solución ergonómica exitosa es aquella que entiende que el entorno debe adaptarse a la persona, y nunca al revés.

Invitamos al lector a recorrer estas páginas no solo como un compendio de ciencia aplicada, sino como un testimonio del compromiso colectivo por humanizar el trabajo. Que estos estudios sirvan de puente para que la técnica y el corazón se encuentren, asegurando que el futuro del trabajo en nuestra región sea, ante todo, un futuro donde el bienestar humano sea el indicador más importante del éxito.

Enrique de la Vega Bustillos
Marzo de 2026

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DEVELOPMENT OF AN ANTHROPOMETRIC DATABASE FOR ASPARAGUS PACKAGING PERSONNEL

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RESUMEN: En esta fase inicial se registraron dimensiones antropométricas de trabajadores agrícolas que desempeñan labores como empacadores de espárrago, con el objetivo de construir una base de datos antropométrica que sirva como base para una segunda etapa del proyecto.

Esta base de datos permitirá, en trabajos posteriores, el diseño de estaciones de trabajo y herramientas ajustables, acordes con las capacidades y necesidades físicas de los trabajadores, desde un enfoque de ingeniería ergonómica.

La disponibilidad de una base de datos antropométrica de los trabajadores del empaque de espárrago de la región de H. Caborca, Sonora, resulta importante para el diseño adecuado de estaciones y herramientas de trabajo. Dicho análisis busca evitar que el trabajador tenga que adaptarse a condiciones laborales inadecuadas y, por el contrario, que el entorno de trabajo se adapte al trabajador, reduciendo riesgos ergonómicos y mejorando la eficiencia y el bienestar laboral.

Palabras claves: antropometría, ergonomía, trabajadores, empaque de espárrago, agricultura.

Relevancia para la ergonomía: El presente estudio permitió generar una base de datos antropométrica de la población laboral dedicada al empaque de espárrago en la costa de Caborca, Sonora, México. Esta información constituye una aportación relevante tanto para la región como para el país, al proporcionar datos confiables que pueden ser utilizados en el diseño ergonómico de estaciones de trabajo y herramientas, así como en la planificación de estrategias para mejorar la salud y seguridad laboral. Asimismo, esta base de datos abre oportunidades para futuras investigaciones relacionadas con la antropometría aplicada, la ergonomía agrícola y la optimización de los procesos productivos.

Abstract: In this initial phase, anthropometric measurements were taken of agricultural workers who perform tasks such as packing asparagus, with the aim of

building an anthropometric database that will serve as the basis for the second stage of the project.

This database will enable the design of adjustable workstations and tools in subsequent work, in line with the physical capabilities and needs of workers, from an ergonomic engineering perspective.

The availability of an anthropometric database of asparagus packers in the H. Caborca region of Sonora is important for the proper design of workstations and tools. This analysis seeks to prevent workers from having to adapt to inadequate working conditions and, instead, to ensure that the working environment adapts to the worker, reducing ergonomic risks and improving efficiency and well-being at work.

Keywords: anthropometry, ergonomics, workers, asparagus packaging, agriculture

Relevance for ergonomics: This study enabled the creation of an anthropometric database of the workforce engaged in asparagus packing on the coast of Caborca, Sonora, Mexico. This information constitutes a significant contribution to both the region and the country, providing reliable data that can be used in the ergonomic design of workstations and tools, as well as in the planning of strategies to improve occupational health and safety. Likewise, this database opens up opportunities for future research related to applied anthropometry, agricultural ergonomics, and the optimization of production processes.

1. INTRODUCTION

In the Caborca region of Sonora, Mexico, one of the main agricultural crops is asparagus, an activity that generates approximately 20,000 jobs and whose demand has a significant impact on the local and regional economy (Nicols, 2024). According to data from the Office of Agricultural and Fisheries Information (OIAPEs) and the Ministry of Agriculture, Livestock, Water Resources, Fisheries, and Aquaculture (SAGARHPA), in 2023, 8,835 hectares were planted in the municipality of Caborca, reaching a production of 90,650 tons, with an economic value of \$3,714,316.00 pesos, which positions the region as the main producer at the regional, state, and national levels.

The asparagus production process begins with harvesting or cutting in the field; this is followed by the packaging stage, which is the main focus of this research. Packaging represents the final form in which the product will be marketed and exported. At this stage, it is essential to consider the requirements of international customers, as asparagus is shipped to various countries, each with its own requirements in terms of size, thickness, and presentation of the product, determined by cultural and commercial preferences.

In this regard, the human factor plays a key role, as packers are responsible for sorting asparagus by thickness, cutting it to the required size, and packing it manually. This work requires repetitive movements, prolonged postures, and manual precision, which increases the likelihood of ergonomic risks.

Decent work is work that respects the needs of workers, without discrimination, with access to social security, a living wage, and optimal health and safety conditions that prevent occupational hazards (Federal Labor Law, 2022). However, as it is a manual process, packing asparagus can cause musculoskeletal injuries if proper ergonomic practices are not implemented, affecting muscles, tendons, joints, and nerves, and causing conditions such as carpal tunnel syndrome, tendinitis, bursitis, and lower back pain, among others.

Several studies have pointed out that neck and shoulder disorders are common in both men and women, associated with physical and psychosocial factors, as well as lifestyle. Among the main risk factors are repetitive hand and finger movements, monotonous tasks, and uncomfortable or forced postures during the workday (Fredriksson et al., 2002).

The main function of anthropometry is to determine the measurements of the human body, and its application has proven to be a very useful tool in ergonomic design. One example is the study conducted in Guayaquil, Colombia, where anthropometric measurements were taken of workers in a beverage industry with the aim of designing workstations that would increase productivity and reduce ergonomic risks (Freire Freire, 2024). Similarly, research such as that by Arrocha et al. (2024) testify to the usefulness of anthropometric indicators in assessing blood pressure alterations in adolescents, while the work of Borda Yusty et al. (2024) focused on identifying musculoskeletal disorders in informal workers in the coffee sector in Colombia, with the aim of proposing strategies for reduction.

Ergonomics, as a discipline, covers multiple areas of application. Studies such as that by Ramírez (2006) evaluated the mining population in the central highlands of Peru using anthropometric measurements, while Bahr-Ulloa et al. (2023) applied anthropometry in ultrasound techniques to assess body composition. Similarly, Donates González et al. (2022) developed an anthropometric study aimed at redesigning workplaces with the purpose of improving safety, health, and labor productivity.

In this first stage of the research, priority is given to recording the anthropometric measurements of workers involved in asparagus packaging, with the aim of preventing, reducing, or eradicating musculoskeletal injuries and disorders resulting from poor posture and excessive physical exertion during the packaging process in later stages.

The data obtained will provide a more accurate picture of the physical capabilities, ranges, and limitations of workers, facilitating the design of adjustable tools and workstations that adapt to their needs and avoid unnecessary strain. This promotes harmony between workers and their work environment, encouraging natural postures and efficient movements that reduce the likelihood of injury.

These considerations support the relevance of this research, which seeks to contribute to improving the quality of life of asparagus packing workers in the Caborca region of Sonora, Mexico, by generating an anthropometric database that will serve as the basis for the design of optimal workstations and tools, which are essential for the efficient and sustainable performance of agricultural activity in the region.

2. OBJECTIVE

Using research methodologies and specialized anthropometric equipment, this first stage seeks to generate an anthropometric database of agricultural workers who work in asparagus packing on the coast of Caborca, Sonora, Mexico. This information will serve as the basis for the second and third stages of the study, in which the design of workstations and/or ergonomic tools will be developed, aimed at facilitating work tasks and significantly reducing the risks of injuries and musculoskeletal disorders associated with the work environment.

3. DELIMITATION.

The study has certain limitations associated with the seasonality of asparagus cultivation, which has a relatively short production period. In the case of Caborca, depending on weather conditions, the season lasts approximately four months, generally from December to March. This situation makes it difficult to collect data during the production period, in addition to increasing the logistical costs associated with transportation to the harvest site.

4. METHODOLOGY.

4.1 Introduction.

For the recording of anthropometric data of workers engaged in asparagus packaging in the coastal region of Caborca, Sonora, Mexico, the measurement procedures and criteria established in the publication of the National Aeronautics and Space Administration (NASA): Anthropometric Source Book, Vol. I: Anthropometry for Designers (Anthropology Research Project, 1978) will be considered.

4.2 Description of the method.

The data were obtained through a cross-sectional observational study, based on a convenience sample of 100 workers engaged in asparagus packaging on the coast of Caborca, Sonora, Mexico.

4.3 Materials.

The following equipment was used to conduct the research:

- Two Lafayette anthropometers, models 01140, 01290, and 01291.
- Two Clarita anthropometric kits.
- One Seca stadiometer.
- One Seca analog scale.

- Two Powerlock Stanley flexometers.
- Two flexible measuring tapes.
- One computer for recording information.

The methodology for obtaining anthropometric measurements was developed as follows. Data collection was carried out by two work teams, each consisting of two researchers; one of them took the measurements, while the other recorded the information obtained.

Participants were randomly selected from among workers performing their usual activities as asparagus packers. The subjects were summoned in pairs by the production supervisor to have their measurements taken in a designated area within the nursing station, ensuring adequate conditions for data collection without interfering with operational tasks.

Prior to data collection, each participant was informed of the study's objective, the measurement procedure, and the use of the data. All workers gave their informed consent, and the confidentiality and anonymity of the information collected was guaranteed. The study was conducted in accordance with ethical research principles, respecting the dignity, integrity, and rights of the participants.

The 24 anthropometric variables recorded, presented in Table 1, correspond to the case study of this work. All measurements were taken with the workers in a standing position, strictly following the procedures established in the National Aeronautics and Space Administration (NASA) reference work: Anthropometric Source Book, Vol. I: Anthropometry for Designers (Anthropology Research Project, 1978).

Table 1. Measures recorded in the study.

Code	Name of the measure
N920	Weight
N805	Height
N328	Height at standing eye level
N23	Height at standing shoulder level
N309	Height at standing elbow level
N949	Height at standing waist level
N398	Height at standing buttock level
N973	Height at standing wrist level
N265	Height at standing middle finger level
N797	Width of arms extended
N798	Width from elbows to center of chest
N80	Arm length relative to wall
N122	Width of standing shoulders
N223	Width of standing chest
N457	Width of standing hips
N144	Distance from ear to ear above the head
N427	Width of the head

N441	Length of the head
N420	Length of the hand
N656	Length of the palm
N411	Width of the palm
N402	Grip diameter (inside)
N529	Height from the floor to the knee
N381	Length from the elbow to the middle finger

5. ANALYSIS OF RESULTS.

The results of the anthropometric measurements of the agricultural population engaged in asparagus packing in the Caborca region of Sonora, Mexico, are presented below. The sample consisted of 100 workers, of whom 64% were men and 36% were women.

The average age of the men was 25, ranging from 18 to 40 years. The average age of the women was 26, ranging from 20 to 40 years.

The anthropometric measurements recorded are presented in Table 2 for men and Table 3 for women. Both tables include the 5th, 50th, and 95th percentiles, as well as the maximum and minimum values for each measurement.

The data were analyzed using Microsoft Excel. Weight measurements are expressed in kilograms, while the rest of the measurements were recorded in centimeters.

Table 2. Results obtained from the 64 men enrolled in the study of agricultural workers involved in asparagus packaging on the coast of Caborca, Sonora, Mexico.

Code	Name of the measure	Percentiles			Minimum	Maximum
		5%	50%	95%		
N920	Weight	53	65	87	50	98
N805	Height	156	163	173	155	177
N328	Height at standing eye level	143	151	163	141	166
N23	Height at standing shoulder level	129	135	144	129	149
N309	Height at standing elbow level	98	102	111	97	118
N949	Height at standing waist level	85	90	97	80	100
N398	Height at standing buttock level	65	75	83	65	87
N973	Height at standing wrist level	74	79	85	73	93
N265	Height at standing middle finger level	61	64	73	60	76
N797	Width of arms extended	154	163	179	87	182

N798	Width from elbows to center of chest	41	68	87	33	94
N80	Arm length relative to wall	71	80	85	70	88
N122	Width of standing shoulders	42	45	50	40	52
N223	Width of standing chest	28	31	34	28	37
N457	Width of standing hips	31	34	38	30	39
N144	Distance from ear to ear above the head	16	18	20	16	21
N427	Width of the head	10	15	17	10	47
N441	Length of the head	23	24	30	22	56
N420	Length of the hand	17	18	19	12	19
N656	Length of the palm	9	10	11	9	11
N411	Width of the palm	8	9	10	7	10
N402	Grip diameter (inside)	3	4	4	3	4
N529	Height from the floor to the knee	42	46	51	39	60
N381	Length from the elbow to the middle finger	42	44	47	40	48

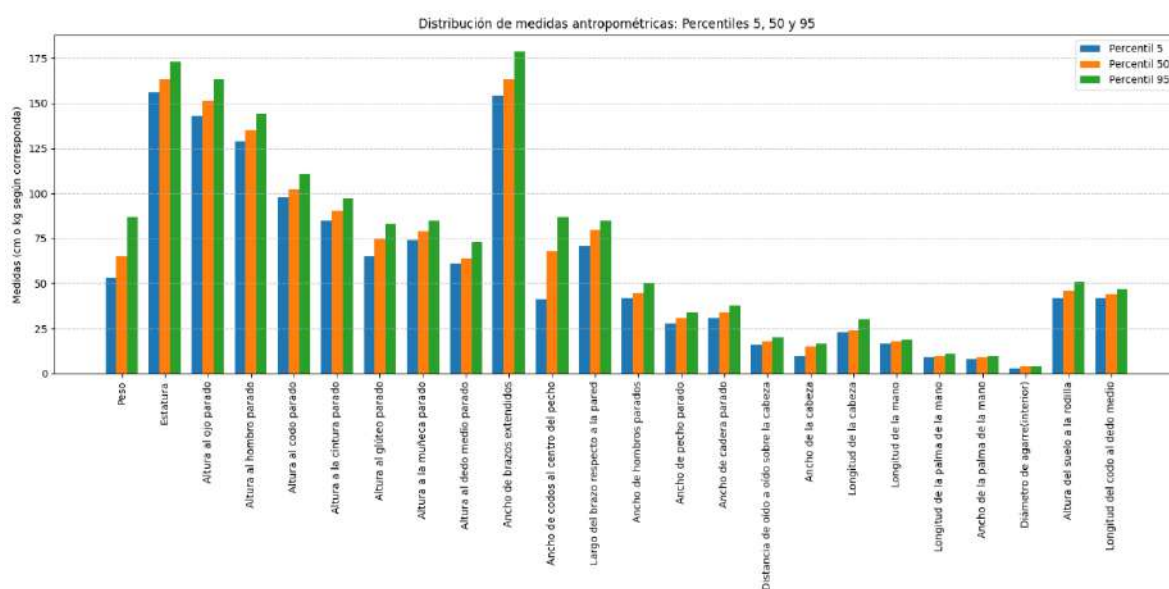
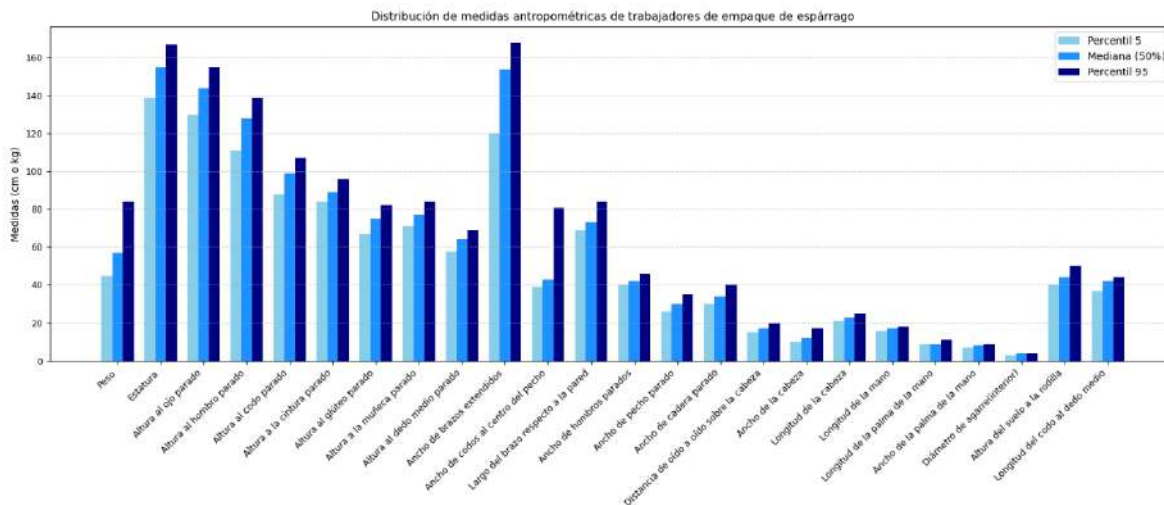


Figure 1: Distribution of anthropometric measurements, percentile 5, 50 and 95

Table 3. Results obtained from the 36 women registered in the study of female agricultural workers involved in asparagus packaging on the coast of Caborca, Sonora, Mexico.

Code	Name of the measure	Percentiles			Minimum	Maximum
		5%	50%	95%		
N920	Weight	45	57	84	42	85
N805	Height	139	155	167	138	172
N328	Height at standing eye level	130	144	155	127	159
N23	Height at standing shoulder level	111	128	139	102	143
N309	Height at standing elbow level	88	99	107	85	109
N949	Height at standing waist level	84	89	96	77	99
N398	Height at standing buttock level	67	75	82	60	87
N973	Height at standing wrist level	71	77	84	70	84
N265	Height at standing middle finger level	58	64	69	57	70
N797	Width of arms extended	120	154	168	88	170
N798	Width from elbows to center of chest	39	43	81	37	82
N80	Arm length relative to wall	69	73	84	64	88
N122	Width of standing shoulders	40	42	46	38	51
N223	Width of standing chest	26	30	35	24	37
N457	Width of standing hips	30	34	40	25	40
N144	Distance from ear to ear above the head	15	17	20	14	27
N427	Width of the head	10	12	17	9	17
N441	Length of the head	21	23	25	21	25
N420	Length of the hand	16	17	18	15	19
N656	Length of the palm	9	9	11	8	11
N411	Width of the palm	7	8	9	7	9
N402	Grip diameter (inside)	3	4	4	3	4
N529	Height from the floor to the knee	40	44	50	38	52
N381	Length from the elbow to the middle finger	37	42	44	32	45



6. CONCLUSIONS AND RECOMMENDATIONS.

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ERGONOMICS AND THE SAFEGUARDING OF THE HUMAN: ONTOLOGICAL AND EPISTEMOLOGICAL ASSUMPTIONS OF PRESCRIBED WORK FROM A MACROERGONOMIC PERSPECTIVE

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Resumen:

En el contexto laboral mexicano, los desórdenes músculo – esqueléticos (DMS) constituyen un indicador persistente de deterioro de las condiciones de trabajo. En organizaciones manufactureras y maquiladoras del noroeste de México, esta persistencia resulta paradójica frente a la presencia de procesos estandarizados, manuales operativos y tecnologías formalizadas que, en principio, prometen estabilidad productiva. Sin embargo, el campo evidencia una brecha sostenida entre trabajo prescrito y trabajo real, donde el trabajador despliega estrategias corporales, cognitivas y emocionales para sostener la producción bajo exigencias no previstas por el diseño formal.

El objetivo de este estudio fue analizar, desde la perspectiva ontológica y epistemológica de la macroergonomía sociotécnica, los marcos conceptuales que estructuran el diseño del trabajo prescrito en la industria manufacturera y maquiladora del noroeste de México, estableciendo en qué medida resultan insuficientes para integrar la variabilidad humana como recurso productivo y cómo contribuyen a configurar una brecha persistente entre trabajo prescrito y trabajo real asociada al malestar ocupacional y a los DMS. La investigación adoptó un enfoque crítico–pragmático, integrando análisis documental y hermenéutico del discurso organizacional, contrastación etnográfica entre prescripción y actividad real, evaluación biopsicosocial de carga física y mental, y talleres de ergonomía participativa.

Los resultados muestran que el sistema productivo se estructura sobre una ontología reduccionista del trabajador y una epistemología prescriptiva que privilegia el conocimiento formalizado por encima del saber situado. Esta configuración invisibiliza la variabilidad humana (fisiológica, cognitiva y emocional) como condición estructural de la producción, amplificando la brecha entre tarea prescrita y actividad real. En el plano operativo, se identificaron patrones de monotonía postural, repetitividad, ciclos cortos, esfuerzo estático, vibración y alta

demanda de precisión, asociados a sobrecarga acumulativa y malestar ocupacional. Se formalizó un modelo estructural que vincula la insuficiencia conceptual con el incremento de la brecha prescrito–real, el aumento de carga biomecánica y la elevación de la probabilidad de DMS, con impactos organizacionales en ausentismo, rotación y costos indirectos.

Se concluye que la persistencia de DMS no es un efecto inevitable de la competitividad industrial, sino un fenómeno emergente de marcos conceptuales insuficientes. La integración explícita de la variabilidad humana y del conocimiento situado en el diseño macroergonómico permite reducir la brecha prescrito–real y avanzar hacia configuraciones productivas más estables y socialmente justas.

Palabras clave: Macroergonomía sociotécnica; trabajo prescrito y trabajo real; variabilidad humana; justicia ocupacional.

Relevancia para la ergonomía: La principal aportación de este estudio a la ergonomía consiste en integrar explícitamente el análisis ontológico y epistemológico como dimensión estructural del diseño macroergonómico del trabajo. Mientras que gran parte de la literatura en desórdenes musculoesqueléticos se concentra en factores biomecánicos, posturales u organizacionales aislados, esta investigación demuestra que dichas manifestaciones son efectos emergentes de marcos conceptuales insuficientes que invisibilizan la variabilidad humana como recurso productivo.

El trabajo amplía el campo de la macroergonomía sociotécnica al formalizar un modelo estructural que articula marco conceptual, organización técnica, actividad real y efectos en salud, estableciendo relaciones lógicas explícitas entre la brecha prescrito–real, la carga biomecánica acumulativa y la probabilidad de desórdenes musculoesqueléticos. Esta formalización contribuye a dotar de mayor rigor teórico a la disciplina, al traducir categorías filosóficas en arquitectura conceptual susceptible de análisis y contraste empírico.

Asimismo, la investigación reubica la discusión sobre competitividad y salud laboral en un plano no antagónico. Al evidenciar que la integración de la variabilidad humana y del conocimiento situado reduce la brecha estructural y estabiliza el desempeño organizacional, el estudio aporta un argumento macroergonómico a favor de configuraciones productivas que armonicen eficiencia, estabilidad y dignidad. En este sentido, la justicia ocupacional se plantea como condición sistémica derivada de la coherencia entre concepción del ser humano, diseño técnico y actividad real.

Finalmente, el estudio ofrece una contribución metodológica al articular análisis hermenéutico-conceptual, contraste etnográfico y evaluación biopsicosocial en un mismo marco interpretativo. Esta integración permite superar la fragmentación entre ergonomía física, cognitiva y organizacional, proponiendo una lectura sistémica capaz de abordar simultáneamente salud, organización y fundamentos conceptuales del trabajo industrial contemporáneo.

Abstract: Work-related musculoskeletal disorders (WMSDs) remain a persistent indicator of deteriorating working conditions in Mexico. In manufacturing and export-

oriented maquiladora organizations in Northwestern Mexico, such persistence appears paradoxical given the widespread use of standardized processes, operating manuals, and formalized production technologies that ostensibly aim at stability and efficiency. Field evidence, however, reveals a sustained gap between prescribed work and real work, in which workers deploy bodily, cognitive, and emotional regulation strategies to sustain production under demands not accounted for in formal design.

This study aimed to analyze, from the ontological and epistemological perspective of sociotechnical macroergonomics, the conceptual frameworks structuring prescribed work design in Northwestern Mexico's manufacturing and maquiladora industry, determining to what extent these frameworks are insufficient to integrate human variability as a productive resource and how they contribute to a persistent prescribed–real work gap associated with occupational distress and WMSDs. A critical–pragmatic approach was adopted, integrating documentary and hermeneutic analysis of organizational discourse, ethnographic contrast between prescription and situated activity, biopsychosocial assessment of physical and mental workload, and participatory ergonomics workshops.

Findings indicate that the production system is shaped by a reductionist ontology of the worker and a prescriptive epistemology that privileges formalized knowledge over situated know-how. This configuration renders human variability (physiological, cognitive, and emotional) structurally invisible, thereby enlarging the prescribed–real work gap. At the operational level, patterns of postural monotony, repetitiveness, short cycle times, static effort, vibration, and high precision demands were identified, consistent with cumulative overload and occupational distress. A structural model was formalized linking conceptual insufficiency to an increased prescribed–real gap, higher biomechanical load, and a growing probability of WMSDs, with organizational impacts expressed in absenteeism, turnover, and hidden costs.

The study concludes that WMSDs are not an inevitable byproduct of industrial competitiveness but an emergent outcome of insufficient conceptual frameworks. Explicitly integrating human variability and situated knowledge into macroergonomic design can reduce the prescribed–real gap and foster more stable and socially just productive configurations.

Keywords: Macroergonomics; prescribed and real work; human variability; occupational justice.

Relevance to Ergonomics: The primary contribution of this study to ergonomics lies in the explicit integration of ontological and epistemological analysis as a structural dimension of macroergonomic work design. While much of the literature on musculoskeletal disorders focuses on isolated biomechanical, postural, or organizational factors, this research demonstrates that such manifestations are emergent effects of insufficient conceptual frameworks that render human variability invisible as a productive resource.

This work advances sociotechnical macroergonomics by formalizing a structural model that articulates conceptual framework, technical organization, real

activity, and health outcomes, establishing explicit logical relationships between the prescribed–real work gap, cumulative biomechanical load, and the probability of musculoskeletal disorders. This formalization contributes to strengthening the theoretical rigor of the discipline by translating philosophical categories into a conceptual architecture that is open to empirical examination and analytical refinement.

Moreover, the study repositions the debate on competitiveness and occupational health beyond a dichotomous perspective. By demonstrating that the integration of human variability and situated knowledge reduces structural divergence and stabilizes organizational performance, the research provides a macroergonomic argument in favor of productive configurations that harmonize efficiency, stability, and human dignity. In this sense, occupational justice is framed not as a normative aspiration, but as a systemic condition derived from coherence between the conception of the human being, technical design, and real work activity.

Finally, the study offers a methodological contribution by articulating hermeneutic–conceptual analysis, ethnographic contrast, and biopsychosocial assessment within a unified interpretative framework. This integration helps overcome the fragmentation between physical, cognitive, and organizational ergonomics, proposing a systemic approach capable of simultaneously addressing health, organization, and the conceptual foundations of contemporary industrial work.

1. INTRODUCTION

This research is grounded in a verifiable empirical fact: the sustained increase of work-related musculoskeletal disorders (WMSDs) in the Mexican labor context. According to the Statistical Report of the Mexican Social Security Institute (IMSS), registered cases rose from 7,382 in 2017 to 10,544 annually in 2024, with a notable rebound following the critical pandemic period. Dorsopathies, carpal tunnel syndrome, and shoulder injuries lead to occupational morbidity, associated with repetitiveness, static load, and awkward postures. This pattern indicates that the phenomenon is not contingent, but structural in work design.

The paradox becomes evident when observing that a significant proportion of manufacturing organizations in Northwestern Mexico operate under formally optimized schemes: standardized processes, international certifications, and continuous improvement methodologies linked to lean production. From the perspective of scientific management inaugurated by Taylor (1911) and later refined through Fordism, standardization is conceived as a guarantee of efficiency. However, the persistence of WMSDs calls into question the sufficiency of this paradigm when applied to complex human systems.

Sociotechnical macroergonomics, developed by Trist and Emery (1960), posits that productive systems are configurations in which technical and social dimensions must be jointly optimized. When design privileges only the technical subsystem, misalignments emerge that manifest as human wear and deterioration. Daniellou (2005) emphasizes that the distinction between prescribed work and real

work constitutes a fundamental analytical tool for understanding such divergences. Prescribed work organizes the task abstractly; real work emerges within the concrete variability of activity.

The Ethnographic analysis in maquiladora environments confirms this difference. Operators deploy bodily, cognitive, and emotional strategies to sustain production under second-based cycles. Dejours (1998) demonstrates that suffering at work arises when organizational structures deny recognition of workers' practical intelligence. In this sense, human variability is not a system anomaly, but a functional condition of its operation.

Karasek's (1979) demand-control theory adds another interpretive dimension: high demands combined with low autonomy increase the probability of physical and mental deterioration. In maquiladora contexts characterized by minimal operational autonomy and constant quota pressure, organizational structure may amplify the risk of WMSDs and occupational stress. Thus, the phenomenon cannot be reduced to isolated biomechanical factors.

The Wisner's (1995) concept of anthropotechnology warns of the risks of transferring technologies and design standards without adaptation to local anthropometric and sociocultural contexts. In regions where productive technologies are imported under external parameters, insufficient adjustment may impose disproportionate demands on the bodies of Mexican workers. Biological and cultural variability becomes subsumed under average-based models.

High labor turnover introduces the so-called "healthy worker effect," described in occupational epidemiology, whereby the most affected individuals exit the system and are replaced by apparently healthy workers. This mechanism preserves immediate productivity while concealing accumulated deterioration and limiting statistical visibility of structural damage.

In this context, the problematic situation does not lie solely in the increase of WMSDs, but in the coexistence of advanced technical formalization with sustained deterioration of occupational health. Empirical evidence suggests the existence of a persistent gap between prescribed and real work, whose explanation exceeds the operational level and refers to the conceptual assumptions guiding work design.

The scientific problem is therefore formulated in epistemological and ontological terms ¿What conception of the worker and what notion of knowledge underlines work design in the maquiladora industry of Northeastern Sonora, and to what extent are these assumptions insufficient to integrate human variability and prevent the structural persistence of WMSDs?

This question does not presuppose an intrinsic incompatibility between competitiveness and health but rather interrogates the sufficiency of the prevailing conceptual frameworks. From the systemic perspective of macroergonomics, recognizing human variability as a productive resource implies moving from a prescriptive epistemology—centered on manuals and standards—toward a situated epistemology that incorporates the knowledge emerging from real activity.

Al problematizing these foundations, the research situates itself within a scientifically grounded critical stance. It does not question the necessity of industrial efficiency, but rather the conceptual reduction that renders human complexity invisible. In this line, ergonomics is conceived not only as a technique for risk

correction, but as a field capable of reviewing the conceptual bases of productive design and of contributing to sociotechnical configurations more coherent with the dignity and health of the worker.

2. OBJECTIVES

General objective: To analyze, from the ontological and epistemological perspective of sociotechnical macroergonomics, the conceptual frameworks structuring prescribed work design in Northwestern Mexico's manufacturing and maquiladora industry, determining to what extent these frameworks are insufficient to integrate human variability as a productive resource and how they contribute to configuring a persistent gap between prescribed and real work associated with occupational distress and musculoskeletal disorders (WMSDs).

Specific objectives:

1. Delimit the theoretical framework of sociotechnical macroergonomics through a critical review of its ontological and epistemological foundations, establishing conceptual criteria to evaluate the adequacy of work design models in relation to human variability.
2. Examine the conceptual frameworks guiding prescribed work design in manufacturing and maquiladora organizations in Northwestern Mexico, identifying implicit assumptions regarding the worker, productivity, and organizational knowledge.
3. Establish the relationship between these conceptual frameworks and the persistent configuration of the prescribed–real work gap, analyzing how the invisibilization of human variability as a productive resource is linked to occupational distress and WMSDs.

3. METHODOLOGY

The research is framed within a critical–interpretative approach with empirical grounding, articulated from sociotechnical macroergonomics and enriched by contributions from critical labor theory. Epistemologically, the study assumes that work design is neither a neutral act nor an exclusively technical one, but rather a social practice grounded in conceptual frameworks that contain ontological assumptions about the nature of the worker and epistemological assumptions about what knowledge is considered legitimate for organizing production. From this perspective, the analysis does not limit itself to describing working conditions but seeks to reconstruct and problematize the conceptual foundations that structure prescribed work in the manufacturing and maquiladora industry of Northeastern Sonora.

The methodological design articulates conceptual, hermeneutic, and empirical procedures within an integrative logic that makes it possible to contrast organizational discourse, productive practice, and effects on health. In a first stage,

an ontological–epistemological reconstruction of formal work design is developed through the critical review of operating manuals, job profiles, standardized procedures, institutional guidelines, and internal regulatory documents. This analysis does not limit itself to identifying technical content, but examines organizational language, the categories used to describe the worker, and the implicit assumptions regarding productivity, efficiency, and control. The objective is to identify the underlying model of the productive subject and to evaluate its coherence with the principles of sociotechnical macroergonomics.

Simultaneously, the regional environment is characterized through the PESTE model, considering political, economic, sociocultural, technological, and ecological factors that condition the configuration of the ergonomic system. This contextual analysis makes it possible to situate the identified conceptual frameworks within a specific productive rationality linked to processes of industrial globalization, technological transfer, and cost competition. The integration of documentary analysis with the study of the regional environment enables an understanding of how models of scientific work organization and lean production logics materialize in concrete sociotechnical configurations.

Subsequently, a hermeneutic contrast between prescribed work and real work is developed. Prescribed work is analyzed technically through the decomposition of procedures, standard times, production quotas, and required competency profiles. This analysis makes it possible to identify the formal expectations of the system regarding worker performance and the assumptions of standardization that sustain it. Thereafter, an ethnographic approach to real activity is conducted through direct observation on the shop floor and the recovery of workers' narratives, with the purpose of documenting the bodily, cognitive, and emotional strategies deployed to sustain production under conditions of high demand. The interpretative approach allows for understanding that human variability does not constitute a deviation from the system, but rather an indispensable regulatory mechanism for its functioning. Improvised postural adjustments, informal redistributions of tasks, modulations of work rhythm, and selective attention strategies are analyzed as situated responses to the limitations of formal design. This contrast reveals the structural distance between the prescriptive model and effective practice, showing how work organization tends to render human variability invisible as a productive resource.

In a third stage, a biopsychosocial assessment with a participatory focus is incorporated, making it possible to evidence the consequences of such invisibilization in terms of occupational distress and musculoskeletal disorders (MSDs). Recognized methods for evaluating physical and biomechanical workload are applied, as well as instruments for assessing mental workload and stress, not with an exclusively diagnostic purpose, but as tools for empirically linking system demands with manifestations of physical and psychosocial deterioration. The results obtained are interpreted in light of the previous conceptual analysis, establishing correspondences between organizational design, the prescribed–real gap, and health effects.

This phase incorporates participatory ergonomics workshops that make it possible to validate the findings and recover the worker's situated knowledge as a legitimate source for understanding the system. The active participation of operators

enables a contrast between formal rationality and lived experience, strengthening the critical interpretation and avoiding decontextualized external readings. The integration of quantitative and qualitative data responds to a logic of methodological triangulation aimed at reinforcing the interpretative validity of the study.

Finally, a critical synthesis is developed in order to evaluate to what extent the conceptual frameworks structuring work design are insufficient to integrate human variability and prevent the persistence of MSDs. This synthesis does not limit itself to formulating technical recommendations but proposes macroergonomic criteria for reviewing the ontological and epistemological foundations of productive design. Guidelines are formulated to harmonize productivity, health, and dignity from a systemic understanding of work, contributing to an ergonomics that not only corrects risk, but conceptually reconfigures the sociotechnical system.

The approach adopted makes it possible to transcend the instrumental application of ergonomic tools and to position the research at the structural level of the conceptual foundations of industrial work. The methodology articulates conceptual analysis, situated interpretation, and empirical evidence within a framework coherent with sociotechnical macroergonomics, ensuring that the study does not reduce itself to an operational diagnosis, but produces critical knowledge about the foundations that sustain the contemporary organization of work in the analyzed regional context.

4. RESULTS

The empirical analysis conducted in manufacturing and maquiladora organizations in Northeastern Sonora made it possible to confirm that musculoskeletal disorders (MSDs) do not emerge as an isolated phenomenon nor as an individual consequence, but rather as a structural result of a sociotechnical system configured by insufficient conceptual frameworks. In terms of the formal model proposed, the productive system can be described as:

$$\mathcal{S} = \{M, O, T, H, E\} \quad (1)$$

where M represents the ontological–epistemological framework, O the organization technical, T prescribed work, H the real human activity and E the emergent effects on health and performance.

The findings show that the determining component is M , whose configuration in the cases studied approximates:

$$M_i = f(\omega_r, \epsilon_p) \quad (2)$$

where ω_r expresses a reductionist ontology of the worker as an interchangeable average operator, and ϵ_p and a prescriptive epistemology that privileges the manual and external standards as the exclusive source of legitimate knowledge.

When the system operates under M_i , an empirical non-integration of human variability was observed:

$$M_i \Rightarrow \neg \text{Integración}(V_h) \quad (3)$$

such that:

$$V_h = \{v_f, v_c, v_e\} \quad (4)$$

where v_f denotes physiological variability, v_c cognitive variability and v_e emotional variability.

Field observations revealed highly repetitive work cycles, prolonged static load, and sustained visual precision demands, confirming that prescriptive design does not incorporate as a structural parameter. This generates a systematic divergence between prescribed work and real activity, formalized as:

$$\Delta_{pr} = H_r - T_p \quad (5)$$

where H_r represents adaptive real activity and T_p the rigid prescribed work. In the analyzed workstations, $\Delta_{pr} > 0$ consistently, indicating that real work requires compensations not foreseen in formal design.

This structural gap translates biomechanically into a cumulative load defined as:

$$C_b = h(\Delta_{pr}, R, E_s) \quad (6)$$

where R represents repetitiveness and E_s sustained static effort. The combination of high motor frequency and low physiological recovery generated conditions consistent with MSD reports documented by the Mexican Social Security Institute (IMSS), particularly in the wrist, shoulder, and lumbar region.

Mental workload records complemented this finding, showing that the activity, although categorized as “unskilled,” requires sustained high concentration. This confirms that V_h is not only physiological, but also cognitive, and its exclusion increases systemic tension.

The model predicts that when cumulative biomechanical load increases, the structural probability of MSDs increases:

$$C_b \uparrow \Rightarrow P(DMS) \uparrow \quad (7)$$

Field data support this relationship, with a correlation observed between workstations with higher repetitiveness and greater reports of musculoskeletal symptomatology.

At the organizational level, the impact is reflected in productive stability. Organizational performance is defined as:

$$D_o = f(P, C, R_t) \quad (8)$$

Where P represents productivity, C costs and R_t turnover. It was verified that the increase of P is associated with increased turnover and absenteeism, generating indirect costs that affect the structural stability of the system:

$$P(DMS) \uparrow \Rightarrow R_t \uparrow \Rightarrow D_o \downarrow \quad (9)$$

This finding confirms that the invisibilization of human variability impacts not only health but also sustained competitiveness.

Participatory workshops made it possible to observe an alternative scenario. When adjustments derived from the worker's situated knowledge were incorporated, a new framework was configured:

$$M_c = f(\omega_h, \epsilon_s) \quad (10)$$

where ω_h represents a humanistic ontology and ϵ_s a situated epistemology.

In these cases, it was observed that:

$$Integración(V_h) \Rightarrow \Delta_{pr} \downarrow \quad (11)$$

and consequently:

$$C_b \downarrow \Rightarrow P(DMS) \downarrow \Rightarrow D_o \uparrow \quad (12)$$

The foregoing demonstrates that competitiveness does not oppose health but rather depends on the conceptual coherence of macroergonomic design.

In summary, the results empirically confirm the structural proposition formulated: In systems where the conceptual framework renders human variability invisible, the gap between prescribed and real work is amplified, increasing the probability of MSDs and reducing productive stability. Conversely, the explicit integration of human variability reconfigures the system toward greater stability and occupational justice.

5. DISCUSSION

The results obtained allow us to maintain that the persistence of musculoskeletal disorders (MSDs) in the manufacturing and maquiladora industry of Northeastern Sonora cannot be explained solely by isolated technical factors or by individual behaviors, but rather by the ontological and epistemological configuration that structures work design. This interpretation aligns with the classical sociotechnical perspective, which recognizes that health effects emerge from the interaction between technical and social subsystems (Trist & Bamforth, 1951) but extends this reading by explicitly incorporating the analysis of the conceptual frameworks that precede organizational design.

The structural model formalized in this study made it possible to demonstrate that the critical variable is not merely repetitiveness or static load, but the systematic

invisibilization of human variability as a structural category. The macroergonomic literature has emphasized the importance of reciprocal adaptation between technology and the human being (Hendrick & Kleiner, 2001); however, in the cases analyzed, adaptation is unilateral: the worker adjusts to the system, not the system to the worker. This asymmetry confirms the presence of a reductionist ontological framework that presupposes physiological homogeneity and cognitive stability.

The persistent gap between prescribed work and real work, formalized as $\Delta_{pr} = H_r - T_p$, acquires in this study a structural character. It does not concern contingent operational deviations, but an inherent difference in prescriptive design. Daniellou (2005) warns that every prescription is necessarily incomplete; however, when such incompleteness is not epistemologically recognized, the gap translates into cumulative biomechanical overload. The empirical evidence confirms that the increase of Δ_{pr} is associated with an increase of C_b and therefore with a greater structural probability of MSDs.

In critical terms, the findings engage with arguments from labor control theory and the intensification of production under Lean Production schemes. Various studies have shown that lean production may increase temporal pressure and psychological load if not accompanied by profound ergonomic redesign. In the analyzed context, the collectivization of quotas did not reduce workload, but rather displaced hierarchical control toward group self-control, generating new forms of emotional tension. This confirms that technological modernization does not automatically imply organizational humanization.

A relevant point in the discussion concerns the relationship between MSDs and competitiveness. Traditionally, it has been assumed that time reduction and rhythm intensification are necessary conditions for maximizing productivity. However, the data show that the increase of $P(DMS)$ is associated with greater turnover (R_t) and indirect costs, affecting organizational performance D_o . These findings question the dominant instrumental rationality and support the structural proposition formulated: sustainable competitiveness depends on the explicit integration of human variability.

The analysis also confirms the existence of the so-called “healthy worker effect,” whereby turnover conceals accumulated deterioration. This phenomenon distorts internal statistics and hinders organizational perception of the problem. From an epistemological perspective, this invisibilization reinforces the insufficient conceptual framework, as the system does not interpret deterioration as a structural failure, but as a natural replacement of labor force. Here, the reductionist ontology articulates with organizational practices that normalize the expulsion of the deteriorated worker.

The study further contributes to the discussion on participatory ergonomics. Field evidence shows that incorporating the worker’s situated knowledge reduces the structural gap and stabilizes the productive process. This finding is consistent with activity-centered ergonomics, which recognizes practical intelligence as a central component of the productive system. However, the present study extends this perspective by formally conceptualizing the integration of V_h as a structural condition of occupational justice.

From an ontological standpoint, the results allow us to affirm that the worker cannot be conceived as a standard operator without generating cumulative physiological tensions. The body is not an interchangeable component of the system, but a biological and cognitive entity with adaptive limits. The structural denial of this condition produces emergent effects expressed in MSDs and occupational distress. This conclusion relocates the problem from the technical domain to the conceptual plane.

From an epistemological standpoint, the discussion shows that prescriptive knowledge formalized in manuals does not exhaust the understanding of work. Situated knowledge emerges as a legitimate source of information for macroergonomic design. When this knowledge is excluded, the system loses self-regulatory capacity and structural divergence increases. Epistemological integration, therefore, is not an optional ethical gesture, but a requirement of systemic coherence.

Finally, the findings support the thesis of occupational justice formulated at the close of the chapter. Justice does not appear here as an abstract normative ideal, but as a structural consequence of coherence between ontology, epistemology, and technical organization. When the conceptual framework shifts from M_i to M_c , the gap is reduced, biomechanical load decreases, and organizational stability increases. This transition does not imply sacrificing competitiveness but reconfiguring it under principles of human integration. In sum, the discussion confirms that the observed MSDs do not constitute inevitable externalities of industrial development, but emergent effects of insufficient conceptual frameworks. Sociotechnical macroergonomics, by explicitly incorporating ontological and epistemological analysis, offers a pathway to overcome this insufficiency and to move toward structurally coherent, sustainable, and just productive systems.

6. CONCLUSIONS

The research made it possible to demonstrate that the persistence of musculoskeletal disorders (MSDs) in the manufacturing and maquiladora industry of Northeastern Sonora does not constitute an isolated phenomenon nor one attributable exclusively to specific technical failures, but rather a structural consequence derived from insufficient conceptual frameworks that organize work design. The empirical evidence confirmed that the invisibilization of human variability as a productive resource configures a persistent gap between prescribed work and real work, whose physiological manifestation translates into cumulative biomechanical overload and occupational distress.

From the sociotechnical macroergonomic perspective, the problem does not lie solely in repetitiveness, static load, or the intensity of the productive rhythm, but in the reductionist ontology that conceives the worker as a standardizable operator and in the prescriptive epistemology that privileges the manual over situated knowledge. This conceptual configuration prevents the explicit integration of physiological, cognitive, and emotional variability into organizational design, amplifying the structural divergence between prescription and real activity.

The formal model developed made it possible to establish that when the integration of human variability tends toward zero, the structural gap increases and the probability of MSDs rise proportionally. Furthermore, it was demonstrated that this condition impacts organizational stability through increased turnover and indirect costs, calling into question the instrumental rationality that assumes productive intensification guarantees sustainable competitiveness.

The findings also showed that incorporating the worker's situated knowledge through participatory mechanisms reduces the structural gap, decreases cumulative biomechanical load, and stabilizes organizational performance. This confirmation demonstrates that competitiveness and health are not antagonistic variables but depend on the ontological–epistemological framework structuring the sociotechnical system.

In theoretical terms, the research contributes a reconfiguration of macroergonomic analysis by explicitly integrating the ontological and epistemological dimension as structuring variables of work design. Occupational justice thus emerges not as an abstract normative aspiration, but as an observable systemic condition when coherence exists between the conception of the human being, technical organization, and real activity.

Consequently, it is concluded that ergonomics, conceived from an expanded sociotechnical perspective, can improve industrial competitiveness without generating negative impact on worker health, provided that macroergonomic design explicitly incorporates human variability as a productive resource. The overcoming of MSDs does not depend exclusively on corrective microergonomic interventions, but on the transformation of the conceptual frameworks that structure the productive system.

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MACROERGONOMICS THEORIES, METHODS, TECHNIQUES, TOOLS, AND SOFTWARE: A SYSTEMATIC LITERATURE REVIEW

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Resumen: La macroergonomía es la disciplina que se enfoca en el diseño y la optimización de los sistemas de trabajo sociotécnicos a nivel organizacional; busca armonizar la interacción entre las personas, la tecnología y la estructura organizacional para mejorar el rendimiento global, la seguridad y el bienestar. Objetivo: determinar, mediante una revisión sistemática de la literatura, los avances de los últimos diez años en teorías, métodos, técnicas, herramientas y software de la macroergonomía.

Método: Se realizó una investigación documental con diseño de revisión sistemática, con alcance descriptivo-analítico, siguiendo las directrices PRISMA 2020. Se incluyeron artículos científicos y de revisión, estudios observacionales y cualitativos publicados entre 2015 y 2025, en inglés o en español, con población trabajadora mayor de 18 años. Se realizó la búsqueda en las bases de datos Web of Science, Scopus, ScienceDirect, Ebsco (Academic Search Ultimate) y Sage Journals.

Se identificaron 468 artículos, de los cuales 45 cumplieron los criterios de inclusión. A partir de la extracción de datos, se construyó una matriz categórica con información de los artículos, como título, autor, año de publicación, país, palabras clave, teorías, modelos, métodos de investigación aplicados, herramientas tecnológicas y software utilizados. Además, se aplicó el enfoque PICO para una lectura transversal y contextual de los textos científicos de la base de datos.

Resultados: La investigación en macroergonomía ha experimentado un auge pospandemia, concentrada principalmente entre 2020 y 2024, con un pico en 2021.

La mayor parte de la producción académica proviene del ámbito anglosajón, liderado por Estados Unidos (46.7%), seguido de Irán, y con una presencia destacada de Colombia, Brasil y México. Predominan los modelos integradores y relacionales, con el modelo socioecológico (24.4%) y el enfoque sistémico (20%). Los enfoques metodológicos que predominan son los cualitativos (62.3%), la investigación-acción participativa y los estudios de caso como métodos principales. Las técnicas o herramientas de recolección de información más utilizadas fueron las entrevistas semiestructuradas (46.7%) y los grupos focales (31.1%). El 64,4 % de los estudios no reportó software; Excel fue la herramienta más mencionada (13.3%), seguido de SPSS y NVivo/Atlas ti (6.7%).

La población de estudio, documentada en los artículos, se centra en trabajadores de entornos organizacionales complejos (docentes y personal sanitario). Las intervenciones buscan el rediseño organizativo mediante enfoques participativos, el modelado sistémico y las tecnologías digitales para transformar la cultura organizacional. La mayoría de los estudios cualitativos (91.1%) carecen de un grupo de comparación. Los resultados indican mejoras en el bienestar, el clima organizacional y el desempeño laboral, lo que impulsa transformaciones significativas.

Conclusión: La macroergonomía se consolida como eje estratégico para transformar sistemas de trabajo complejos, mejorando el bienestar individual y colectivo, el clima organizacional y el desempeño laboral. Sin embargo, persiste una brecha en la estandarización del uso de software y en la inclusión de comparadores en los estudios cualitativos. Se recomienda fortalecer las metodologías mixtas, incorporar herramientas digitales avanzadas y ampliar la transferencia de conocimiento a contextos latinoamericanos.

Palabras clave: Ergonomía, macroergonomía, teorías, métodos, técnicas, herramientas

Relevancia para la ergonomía: Impacto Sistémico: La macroergonomía se posiciona como un eje fundamental al propender a un equilibrio entre el bienestar individual y el colectivo, optimizando el clima organizacional y el desempeño laboral en sistemas de trabajo complejos.

Transferencia de Conocimiento: esta revisión establece una línea de base científica a nivel regional que facilita la transferencia de metodologías exitosas y orienta líneas de investigación basadas en metodología y diseños participativos. Evolución Profesional: El estudio fortalece la toma de decisiones estratégicas de los ergonomistas, brindando herramientas basadas en evidencia para diseñar entornos laborales más seguros, saludables y productivos.

Proyección social y académica: la sistematización de teorías, métodos y herramientas en macroergonomía contribuye a la construcción de políticas públicas y programas institucionales orientados al bienestar. A nivel académico, ofrece insumos para fomentar la formación de profesionales capaces de responder a los retos contemporáneos.

Abstract: Macroergonomics is the discipline that focuses on the design and optimization of socio-technical work systems at the organizational level, seeking to harmonize the interactions among people, technology, and organizational structure to improve overall performance, safety, and well-being.

Objective: To determine, through a systematic literature review, the advances made in the last ten years in macroergonomics theories, methods, techniques, tools, and software.

Method: A documentary research study was conducted using a systematic review design with a descriptive-analytical scope, following the PRISMA 2020 guidelines. Scientific and review articles, observational studies, and qualitative studies published between 2015 and 2025, in English or Spanish, that included a working population aged 18 years or older, were included. The search was conducted in the Web of Science, Scopus, Science Direct, Ebsco (Academic Search Ultimate), and Sage Journals databases.

A total of 468 articles were identified; 45 met the inclusion criteria. Data extraction was performed using a categorical matrix, drawing on information from the articles, including title, author, year of publication, country, keywords, theories, models, research methods applied, technological tools, and software used. In addition, the PICO approach was applied for a cross-sectional and contextual reading of the scientific texts in the database.

Results: Research in macroergonomics has experienced a post-pandemic boom, concentrated mainly between 2020 and 2024, peaking in 2021. Most of the academic output comes from the Anglo-Saxon world, led by the United States (46.7%), followed by Iran, with a notable presence from Colombia, Brazil, and Mexico. Integrative and relational models predominate, with the socio-ecological model (24.4%) and the systemic approach (20%). The predominant methodological approaches are qualitative (62.3%), participatory action research, and case studies. The most commonly used data collection techniques or tools were semi-structured interviews (46.7%) and focus groups (31.1%). Sixty-four point four percent of the studies did not report software; Excel was the most frequently mentioned tool (13.3%), followed by SPSS and NVivo/Atlas ti (6.7%).

The study population documented in the articles focuses on workers in complex organizational environments (teachers, healthcare personnel). The interventions seek to redesign the organization through participatory approaches, systemic modeling, and digital technologies to transform organizational culture. Most qualitative studies (91.1%) lack a comparison group. The results indicate improvements in well-being, organizational climate, and job performance, driving significant transformations.

Conclusion: Macroergonomics is consolidating its position as a strategic axis for transforming complex work systems, improving individual and collective well-being, organizational climate, and job performance. However, a gap persists in the standardization of software use and the inclusion of comparators in qualitative studies. It is recommended to strengthen mixed methodologies, incorporate advanced digital tools, and expand knowledge transfer to Latin American contexts.

Keywords: Ergonomics, macroergonomics, theories, methods, techniques, tools

Relevance to ergonomics: Systemic Impact: Macroergonomics is positioned as a fundamental axis by promoting a balance between individual and collective well-being, optimizing the organizational climate and work performance in complex work systems.

Knowledge Transfer: This review establishes a scientific baseline at the regional level, facilitating the transfer of successful methodologies and guiding lines of research informed by participatory methodologies and designs.

Professional Development: The study strengthens ergonomists' strategic decision-making by providing evidence-based tools to design safer, healthier, and more productive work environments.

Social and Academic Outreach: The systematization of theories, methods, and tools in macroergonomics contributes to the development of public policies and institutional programs aimed at well-being. At the academic level, it provides input to promote the training of professionals capable of responding to contemporary challenges.

1. INTRODUCTION

In 2000, the International Ergonomics Association (IEA) defined ergonomics as a scientific discipline concerned with the understanding of interactions between humans and other elements of a system, and as the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance (IEA, 2000). Ergonomics can focus on microergonomics or macroergonomics. Human factors ergonomics can focus both on the microergonomic aspects of design, such as the design of procedures, context, and the equipment and tools used to perform tasks, and on the macroergonomic aspects of design, such as work organization, types of work, technology used, job roles, communication, and feedback (Wilson, 2014). Likewise, the IEA defined three domains: physical, cognitive, and organizational ergonomics, the latter dealing with socio-technical systems, including their organizational structures, policies, and processes, and with harmonizing the interactions among people, technology, and organizational structure.

This demonstrates the evolution of ergonomics, which not only considers the design of individual workstations but also adopts a holistic perspective that recognizes the interconnection between humans, technology, and organization. The term macroergonomics was introduced by Hal Hendrick, who views it as the fourth phase in the historical evolution of ergonomics and as the subdiscipline that addresses the human-organization-technology interface to improve overall system performance (Hendrick, 1985).

Macroergonomics is a top-down socio-technical systems approach that deals with the analysis, design, and evaluation of work systems (a work system consists of two or more people interacting with some work design, hardware or software, internal or external environment, and organizational design). (Hendrick & Kleiner, Eds., 2002). The main objective of macroergonomics is to harmonize work systems

at both the microergonomic and macroergonomic levels to improve productivity, safety, and health (i.e., the quality of life of employees) (Carrasquero, 2016).

In the Colombian context, the implementation of ergonomics has been gaining recognition. However, when exploring research and developments in this discipline, it has been found that they have been more oriented towards microergonomics, with little exploration of the principles of macroergonomics, where it is important to address the understanding of how organizations approach the design of work systems, what theories, models, methodologies, tools, and software they use, and what the concrete results of these interventions have been (Rodríguez & Pérez, 2016; Rodríguez et al., 2022)

Considering the above, the need was identified to consolidate a systematic state-of-the-art that would enable recognition of the current theoretical and methodological frameworks in macroergonomics; identification of the tools and software used in organizational interventions; and facilitation of knowledge transfer to regional contexts, thereby promoting the replication and adaptation of successful methodologies.

Within this framework, the present study aims to determine, through a systematic review of the literature, the advances made in the last ten years in macroergonomics theories, methods, techniques, tools, and software. To achieve this objective, three complementary lines of action are proposed: to characterize the studies included in the review according to the year and place of publication; to describe the theories and models used, the research methods applied, and the techniques, tools, and software reported; and to analyze the methodological patterns of the studies following the PICO (Population, Intervention, Comparator, Outcome) approach.

This work seeks to consolidate information, provide a baseline for advancing the discipline, specifically in macroergonomics, guide future lines of research, and transfer knowledge and methodologies to different sectors at the business level, encouraging their replication and adaptation. It also aims to strengthen the capacity of ergonomists and related sciences to select evidence-based strategies that address contemporary organizational problems, in favor of safer, healthier, and more productive work environments.

2. OBJECTIVE

Determine, through a systematic literature review, the advances made in the last ten years in macroergonomics theories, methods, techniques, tools, and software.

3. METHODOLOGY

A descriptive documentary research study was conducted using a systematic review design of a descriptive-analytical nature, following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020). The question that guided the search strategy was: What theories, models, methods,

techniques, tools, and software have been documented and implemented in macroergonomics, and what results have been reported as a consequence of their application?

The search was conducted in the Web of Science, Scopus, ScienceDirect, Ebsco (Academic Search Ultimate), and Sage Journals databases, using both free terms and MeSH (Medical Subject Headings) descriptors in Spanish and English. The terms were: macroergonomics, work systems assessment, work systems, sociotechnical systems, participatory processes, participatory ergonomics / macroergonomics, measurement of work systems, work systems, sociotechnical systems, participatory processes, participatory ergonomics.

The article retrieval strategy included articles on research conducted with working populations aged 18 and older, written in English or Spanish, published between 2015 and 2025, and available as scientific or review articles, including systematic reviews, observational studies, and qualitative studies, that could be downloaded through institutional databases. The exclusion criteria used were: articles in languages other than English and/or Spanish; articles published before 2015; and theses and letters to the editor.

During the selection process and the first article filter, duplicate articles were removed, and studies potentially eligible for inclusion in the analysis were identified based on title and abstract review. The researchers independently reviewed the full-text articles for inclusion. In case of disagreement, consensus on inclusion or exclusion was reached through discussion. The selection process yielded 468 articles, and 45 remained after the first filter.

Table 1 below shows the articles found without filtering, with filtering, eliminated due to duplication in the same database or between databases, by keywords, and by abstract.

Table 1. Articles with filters, eliminated, and refined by Title, keyword, and abstract.
Own elaboration

Database	Article found without filtering	Articles found with the filter	Articles refined by discarding duplicates	Articles refined by discarding duplicates between databases	Articles filtered by Title and keywords	Articles filtered by Abstract
Web of Science	60	28	28	28	22	18
Scopus	59	21	14	14	11	11
Science Direct	76	46	13	6	5	5
Sage Journal	273	73	19	18	11	11
Ebsco	0	0	0	0	0	0
Total	468	168	74	66	47	45

For the data extraction process, a categorical matrix was constructed using information from the articles, including title, author, year of publication, country, keywords, theories, models, research methods applied, technological tools, and software used. In addition, the PICO (Population, Intervention, Comparator, Outcome) approach was applied for a cross-sectional and contextual reading of the scientific texts in the database.

The critical evaluation of the studies is conducted independently by the researchers, with discrepancies resolved by consensus. Based on a detailed analysis of the 45 selected articles, the correspondence of each one with the research question defined under the PICO approach was verified.

4. RESULTS

The preliminary results obtained from the initial search for articles are presented below.

The search initially yielded 468 results based solely on the search terms (Figure 1). An initial filter was applied to scientific and review articles published between 2015 and 2025, reducing the number to 168 documents. Subsequently, duplicate articles were removed from both the same databases and between them, leaving a total of 66 articles. The selection of articles by title, keywords, and abstract identified 47 texts for full reading. Finally, two articles were excluded for study design, leaving a total of 45 articles selected for the initial description.

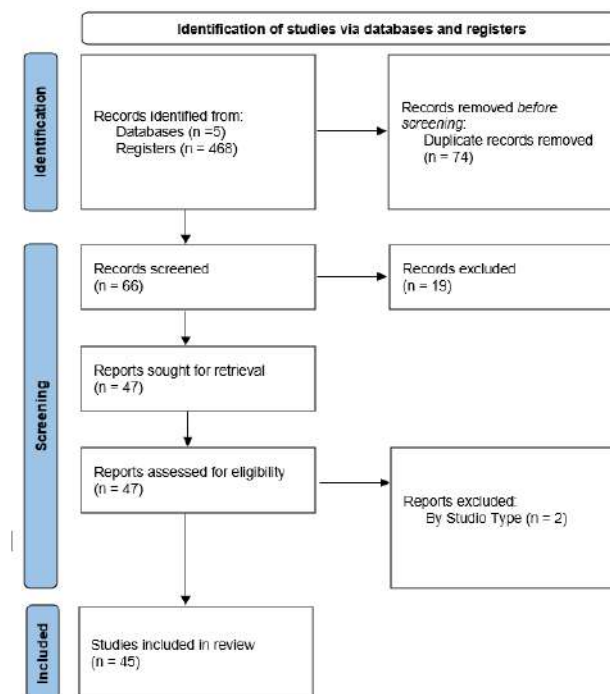


Figure 1. Article selection flowchart, PRISMA 2020 flow diagram

Analysis of Results

During the initial identification, mapping, and coding phase of the systematic review, 45 articles on macroergonomics were analyzed.

The findings of the review allow us to identify several relevant trends in macroergonomics. The results of the objectives for this first stage of the systematic review are presented below.

Geographic and temporal distribution of the review studies.

The characterization carried out identifies a strong concentration of studies in the Anglo-Saxon world, particularly in the United States (46.7%), which accounts for almost half of the publications reviewed. Iran follows with a notable share (17.8%), reflecting its growing academic output in ergonomics and occupational health, and with a notable presence from Colombia, Brazil, and Mexico, which is particularly relevant for research as it integrates frameworks applicable in the regional context (Table 2).

Table 2. Characterization of studies according to place of publication.
Own elaboration

Country/Region	Frequency (n)	Percentage
United States	21	46.7
Irán	8	17.8
Sweden	2	4.4
United Kingdom	2	4.4
Colombia	2	4.4
Brazil	1	2.2
Mexico	1	2.2
Finland	1	2.2
Indonesia	1	2.2
Portugal	1	2.2
Australia	1	2.2
Canada	1	2.2
Norway (Europe)	1	2.2
Persian Gulf	1	2.2
Total	45	100

Chronologically, the highest volume of publications is concentrated between 2020 and 2024, with a peak in 2021 (8 articles), possibly motivated by the need to rethink organizational structures, well-being, and post-pandemic working conditions. This could be indicative of a theoretical-methodological and thematic turning point in the field of macroergonomics (Table 3).

Table 3. Years of publication of the articles. Own elaboration.

Año	(n)	(%)
2014	1	2.2%
2015	2	4.4
2016	3	6.7
2017	4	8.9
2018	4	8.9
2019	3	6.7
2020	5	11.1
2021	8	17.8
2022	5	11.1
2023	4	8.9
2024	6	13.3
Total	45	100%

Theories and Conceptual Models

Regarding the theories and conceptual models used in macroergonomics, a clear predominance of multiscale, integrative, and relational approaches was identified, particularly in ergonomics, health, and institutional education.

The socioecological model (24.4%) and the systemic approach (20.0%) are the dominant frameworks, reflecting a strong inclination to analyze complex phenomena from an interconnected, dynamic perspective. Together, they represent nearly 50% of the database, evidencing a sustained trend toward studying the interactions between the individual, the environment, and the institutional structure (Table 4).

Likewise, activity theory (Engeström) (11.1%), Bronfenbrenner's ecological model (8.9%), and participatory ergonomics (8.9%) are consistently highlighted, reinforcing a relational-contextual view. These models privilege the interaction between subjects, tools, and organizational systems, with special emphasis on

cultural mediation, the agency of social actors, and the value of collaborative processes.

To a lesser extent, but with conceptual relevance, frameworks such as systems ergonomics, the biopsychosocial model, social learning theory, critical theory, and health literacy emerge. Although each appears only once, their inclusion broadens the database's epistemological spectrum and introduces interpretive, sociocultural, and political perspectives into institutional analysis.

Taken together, these findings show a clear commitment to holistic, contextualized, and transformative theoretical models capable of addressing the complexity of human systems from perspectives that integrate the individual, the collective, and the structural.

Table 4. Theories and conceptual models in macroergonomics—own elaboration.

Theory/Model	n	(%)
Socioecological model	11	24.4%
Systemic approach/systemic thinking	9	20.0%
Activity theory (Engeström)	5	11.1%
Bronfenbrenner's ecological model	4	8.9%
Participatory ergonomics	4	8.9%
Systems ergonomics/macroergonomics	3	6.7%
Social learning theory	2	4.4%
Biopsychosocial model	2	4.4%
Other (with 1 mention)	5	11.1%
Total	45	100%

Methodological approaches in macroergonomics

Qualitative approaches predominate in macroergonomics (62.3%), followed by mixed research (22.2%) (Table 5). These approaches enable deep immersion in specific contexts, facilitating the understanding of complex phenomena from a situated, transformative perspective.

Table 5. Type of methodological approach—own elaboration.

Type of methodological approach	Frequency	Percentage (%)
Qualitative	28	62.3
Mixed (Quantitative-qualitative)	10	22.2
Quantitative	6	13.3
Theoretical or systematic review	1	2.2
Total	45	100%

Methods applied in macroergonomics

The studies reviewed show a predominance of qualitative approaches, with case studies (15.6%) and participatory action research (13.3%) standing out as methods for understanding organizational phenomena from a situated perspective. Likewise, methodologies such as grounded theory (11.1%), institutional ethnography (6.7%), and participatory systemic modeling (6.7%) are identified, which provide interpretive depth and allow for the representation of the complexity of socio-technical relationships (Table 6).

These methods reflect an alignment with principles of collaborative and action-oriented research, consistent with frameworks such as participatory ergonomics and systemic thinking. The methodological diversity demonstrates an effort to adapt research designs to the complexity of work systems, although the low frequency of comparative studies limits the possibility of generalizing the results.

Techniques in macroergonomics

In terms of the collection techniques used, semi-structured interviews (46.7%) and focus groups (31.1%) are the most frequent, which favors the collection of narratives rich in meaning and the collective construction of knowledge. Likewise, the integration of reflective journals, participant observation, and documentary analysis is identified, which reinforces a methodological triangulation oriented toward internal validation and interpretive depth (Table 6).

A small group of researchers incorporates innovative techniques such as photo-voice, narrative interviews focused on life trajectories, community timelines, stakeholder maps, and ad hoc questionnaires, combined with qualitative thematic analysis. Although less frequent, these techniques broaden the methodological repertoire and reflect a desire to capture subjective, temporal, and relational dimensions of the phenomena studied.

Table 6. Methods/Techniques used in macroergonomics. Own elaboration.

Methods	Frequency	Percentage
Case study	7	15.6%
Action/participatory research	6	13.3%
Grounded theory	5	11.1%
Participatory systemic modeling	3	6.7%
Ethnography/Institutional ethnography	3	6.7%
Technique	Frequency	Percentage
Semi-structured interview	21	46.7%
Focus group	14	31.1%
Documentary analysis	10	22.2%
Participant/non- participant observation	8	17.8%
Reflective journal	4	8.9%
Other (with ≤ 2 entries)	7	15.6%
The percentages reported correspond to the number of articles in which each technique or method was identified, assuming that a single study could use more than one strategy.		

Tools and Software

The analysis of the review articles shows a limitation in the explicit use of specialized software for data processing, interpretation, or modeling in macroergonomics. Although several studies use structured instruments (such as questionnaires, guides, checklists, or matrices), 64.4% of studies do not report specific digital software, suggesting a lack of standardization in methodological reporting that supports data processing, visualization, or systematization (Table 7).

Table 7. Software used in macroergonomics. Own elaboration.

Category	n	(%)	Authors of articles
Report the use of software	16	35.5	Taghi-Molla et al., 2020), (Saavedra-Robinson et al., 2017), (Zare et al., 2024), (Abdollahpour et al., 2023), (Murphy et al., 2018), (Kalteh & Mokarami, 2021), (Realyvásquez-Vargas et al., 2018), (Wooldridge et al., 2022), (de Vries & Bligård, 2019), (Holden et al., 2015), (Holden et al., 2016), (Holden et al., 2021), (Fazli et al., 2023), (Kalteh et al., 2020), Hoyland et al.2023, Wooldridge et al 2024
No software use reported	29	64.4	
Total	45	100%	

Excel-type spreadsheets, at 13.3%, are the most widely used digital tool among the studies reviewed, as shown in Table 8, followed by statistical software (SPSS) and qualitative tools (NVivo, Atlas ti, CAQDAS), each with 6.7%, reflecting specific applications in psychometric validation processes, factor analysis, or content coding.

To a lesser extent, but with high analytical value, visual and systemic modeling tools such as STELLA and Vensim stand out, with their presence in 4.4% of the studies being strategic due to their alignment with macroergonomic, sociotechnical, and adaptive design approaches. Finally, the use of innovative methods, such as Epistemic Network Analysis (ENA), indicates an incipient methodological sophistication.

Table 8. Digital tools in macroergonomics—own elaboration.

Tool/software category	(n)	(%)
No software use reported	29	64.4%
Spreadsheets (Excel, prioritization matrices, multi-criteria analysis)	6	13.3%
Statistical software (SPSS, factor analysis, Cronbach's alpha, psychometric validations)	3	6.7%
Qualitative tools (CAQDAS, Atlas ti, NVivo, thematic coding, assisted qualitative analysis)	3	6.7%
Visual/systemic modeling tools (Lucidchart, STELLA, Vensim, STAMP Toolkit, Visio)	2	4.4%
Other specific tools (ENA, process mapping, structural diagramming)	2	4.4%
Total	45	100%

Methodological patterns of studies following the PICO approach

The studies primarily focus on workers operating in complex organizational environments, such as teachers, healthcare personnel, administrative staff, and industrial workers. These populations share conditions of exposure to rapid change, adaptive pressure, and structural reorganization, which have motivated the exploration of their experiences, levels of well-being, and perception of the work environment.

Regarding intervention, strategies for organizational redesign through participatory and collaborative approaches have been identified. The most frequent interventions include participatory ergonomics, systemic modeling applied to organizational processes, and the incorporation of digital technologies to optimize working conditions. These actions aim not only to improve performance and mitigate risks but also to transform organizational culture from a care-focused, shared-responsibility, and institutional-learning perspective.

In relation to the comparator, Table 9 shows a marked predominance of qualitative studies without a comparison group (91.1%). This methodological characteristic responds to exploratory and transformative approaches that privilege a deep understanding of specific contexts over the establishment of causal relationships. Only a small group of articles (8.9%) includes some formal comparison, using pre-post intervention designs, inter-institutional contrasts, or differentiated analysis of theoretical categories. These few cases provide useful contrasting evidence, although they remain consistent with qualitative reference frameworks.

In terms of outcomes, most studies report substantive improvements in variables such as individual and collective well-being, organizational climate, and job performance. Beyond operational indicators, the findings highlight processes of participatory strengthening, an increase in institutional actors' sense of agency, and progress toward more adaptive and sustainable organizational structures. Taken together, these results demonstrate an interest in generating significant transformations in organizational systems through interventions that are situated and constructed from within.

Table 9. Comparison of studies in macroergonomics. Own elaboration.

Comparison category	n	(%)	Authors of articles
No comparison made / Not applicable	41	91.1%	
Makes some comparison	4	8.9%	(Lee et al., 2024), (Coelho et al., 2017), (Saavedra-Robinson et al., 2017), (Holden et al., 2015)
Total number of articles analyzed	45	100%	

5. CONCLUSIONS

Macroeconomics is establishing itself as a strategic field for organizational redesign, promoting a balance between individual and collective well-being, improving the institutional climate, and strengthening work performance. Academic output during this period highlights an urgent need to transform work systems and organizational structures through a comprehensive approach that prioritizes systemic well-being in the modern workplace.

The results show that the theories and models used in macroergonomics favor interaction between individuals, tools, and organizational systems, with a special emphasis on cultural mediation, the agency of social actors, and the value of collaborative processes. There is a clear commitment to holistic, contextualized, and transformative theoretical models capable of addressing the complexity of human systems from perspectives that integrate the individual, the collective, and the structural.

At the methodological level, most intervention-oriented designs demonstrate that macroergonomics seeks not only technical observation but also collaborative organizational redesign. These interventions report tangible improvements in well-being, organizational climate, and job performance. However, an exploratory and descriptive orientation predominates, with few comparative designs, which limits the ability to establish robust causalities and generalizable evidence.

Post-pandemic macroergonomics research prioritizes populations in transformation, mainly in health, education, and administration, through structural and technological redesign interventions, with an emphasis on collective well-being and institutional climate. This overview confirms the relevance of macroergonomics as a key discipline for addressing contemporary challenges, but also reveals the need to strengthen mixed methodologies, incorporate advanced digital tools, and expand knowledge transfer to regional contexts.

In summary, macroergonomics is projected as a field in consolidation, providing practical and theoretical solutions for the redesign of work systems. However, it requires greater methodological rigor and standardization to generate comparable, transferable evidence.

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COMPETITIVE STATE ANXIETY AND SHOOTING PERFORMANCE IN UNIVERSITY ARCHERS: MULTILEVEL, MEDIATION AND STRUCTURAL EQUATION MODEL ANALYSES

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Resumen La ansiedad competitiva constituye un factor psicológico clave que influye en el rendimiento en deportes de precisión como el tiro con arco, donde la exactitud y la consistencia motora son fundamentales para lograr resultados exitosos. Este estudio examinó las relaciones entre la ansiedad rasgo, la ansiedad estado competitiva, la estabilidad del rendimiento y la precisión de tiro en arqueros universitarios mediante un enfoque analítico que combinó modelado multinivel y modelado de ecuaciones estructurales. Se empleó un diseño correlacional transversal con una muestra de 65 arqueros universitarios competitivos (37 hombres y 28 mujeres; *media de edad* = 21.4, *DE* = 1.9). La ansiedad rasgo competitiva se evaluó mediante el Sport Competition Anxiety Test (SCAT), mientras que la ansiedad estado se midió inmediatamente antes de la ejecución utilizando el Competitive State Anxiety Inventory-2 (CSAI-2). Los indicadores objetivos de rendimiento se obtuvieron a partir de una tarea estandarizada de tiro compuesta por 30 flechas a una distancia de 18 m en condiciones controladas que simulaban un entorno competitivo.

El modelo de ecuaciones estructurales mostró un buen ajuste global: χ^2 (72) = 92.48, $p = 0.053$, CFI = 0.96, TLI = 0.95, RMSEA = 0.049 (IC 90% [0.000, 0.073]) y SRMR = 0.052. La ansiedad rasgo predijo significativamente la ansiedad estado ($\beta = 0.53$, EE = 0.08, $p < 0.001$). A su vez, la ansiedad estado predijo negativamente tanto la estabilidad del rendimiento ($\beta = -0.42$, EE = 0.10, $p < 0.001$) como la precisión de tiro ($\beta = -0.31$, EE = 0.10, $p = 0.002$). La estabilidad del rendimiento mostró una relación positiva significativa con la precisión de tiro ($\beta = 0.56$, EE = 0.09, $p < 0.001$), lo que indica que los atletas con mayor consistencia entre disparos obtuvieron mayores niveles de precisión global. La ansiedad rasgo también

presentó un efecto directo negativo sobre la estabilidad del rendimiento ($\beta = -0.24$, $EE = 0.09$, $p = 0.013$) y un efecto directo menor sobre la precisión de tiro ($\beta = -0.16$, $EE = 0.01$, $p < 0.001$). El modelo completo explicó el 37% de la varianza en la precisión de tiro ($R^2 = 0.37$) y el 31% de la varianza en la estabilidad del rendimiento ($R^2 = 0.31$).

En conjunto, los resultados indican que la ansiedad estado competitiva desempeña un papel mediador central entre las predisposiciones disposicionales de ansiedad y los resultados objetivos de rendimiento. Niveles elevados de ansiedad se asociaron con mayor variabilidad entre disparos y menor precisión, lo que respalda las predicciones teóricas de los modelos multidimensionales de ansiedad y de la teoría del control atencional. Estos hallazgos subrayan la importancia de implementar estrategias de regulación psicológica orientadas a reducir la ansiedad situacional y mejorar la estabilidad del rendimiento en deportes de precisión.

Palabras clave: Ansiedad competitiva, precisión de tiro, estabilidad del rendimiento, tiro con arco, modelo de ecuaciones estructurales.

Relevancia para la ergonomía: Desde la perspectiva de la ergonomía, los resultados de este estudio pueden aportar evidencia sobre cómo los factores psicológicos, particularmente la ansiedad competitiva, influyen en el control motor fino y la estabilidad del rendimiento en tareas de alta precisión. La ergonomía contemporánea no solo analiza la interacción física entre el ser humano y los sistemas de trabajo, sino también la interacción cognitiva y emocional que puede afectar la eficiencia, la precisión y la seguridad en la ejecución de tareas.

En primer lugar, los hallazgos muestran que el estado de ansiedad se asocia con una disminución significativa de la estabilidad del rendimiento ($\beta = -0.42$, $p < 0.001$) y de la precisión de tiro ($\beta = -0.31$, $p = 0.002$). Desde una perspectiva ergonómica, esto indica que los estados emocionales pueden alterar la coordinación neuromuscular, la regulación de la fuerza y el control postural, factores críticos en actividades que requieren movimientos repetitivos altamente controlados. Estos resultados refuerzan la importancia de considerar variables psicofisiológicas dentro del diseño ergonómico de tareas que demandan precisión.

En segundo lugar, el hecho de que la estabilidad del rendimiento prediga significativamente la precisión de tiro ($\beta = 0.56$, $p < 0.001$) sugiere que la consistencia motora constituye un componente clave del desempeño humano en sistemas hombre-máquina. En ergonomía aplicada, este tipo de evidencia puede contribuir al diseño de entornos de trabajo, interfaces y herramientas que minimicen la carga cognitiva y emocional, permitiendo a los operadores mantener un nivel óptimo de control motor y atención sostenida.

Además, el modelo estructural mostró que el rasgo de ansiedad influye indirectamente en el rendimiento a través del estado de ansiedad, lo que implica que las características individuales del operador deben considerarse dentro del análisis ergonómico. En contextos industriales o tecnológicos donde se requieren altos niveles de precisión, como operaciones quirúrgicas, control de procesos

industriales, o manipulación de instrumentos de alta exactitud, la gestión del estrés y la ansiedad puede ser tan relevante como el diseño físico del sistema.

Finalmente, estos resultados aportan evidencia útil para el desarrollo de intervenciones ergonómicas integrales, que incluyan no solo la optimización del entorno físico y de las herramientas de trabajo, sino también estrategias de regulación emocional, entrenamiento atencional y preparación psicológica. Integrar estos componentes puede contribuir a mejorar la eficiencia, reducir errores humanos y aumentar la estabilidad del rendimiento en tareas críticas de precisión.

Abstract: Competitive anxiety is a critical psychological factor influencing performance in precision sports such as archery, where accuracy and motor consistency are essential for successful outcomes. This study examined the relationships between trait anxiety, competitive state anxiety, performance stability, and shooting accuracy in university archers using a multilevel and structural modeling approach. A cross-sectional correlational design was employed with a sample of 65 competitive university archers (37 males, 28 females; *mean* age = 21.4, *SD* = 1.9). Trait competitive anxiety was assessed using the Sport Competition Anxiety Test (SCAT), while situational anxiety was measured immediately before performance using the Competitive State Anxiety Inventory-2 (CSAI-2). Objective performance indicators were derived from a standardized shooting task consisting of 30 arrows at 18 m under controlled competition-like conditions.

Structural equation modeling demonstrated good overall model fit, $\chi^2 (72) = 92.48$, $p = 0.053$, CFI = 0.96, TLI = 0.95, RMSEA = 0.049 (90% CI [0.000, 0.073]), and SRMR = 0.052. Trait anxiety significantly predicted state anxiety ($\beta = 0.53$, SE = 0.08, $p < 0.001$). State anxiety negatively predicted both performance stability ($\beta = -0.42$, SE = 0.10, $p < 0.001$) and shooting accuracy ($\beta = -0.31$, SE = 0.10, $p = 0.002$). Performance stability showed a strong positive relationship with shooting accuracy ($\beta = 0.56$, SE = 0.09, $p < 0.001$), indicating that athletes with more consistent shot execution achieved higher overall accuracy. Trait anxiety also exerted a direct negative effect on performance stability ($\beta = -0.24$, SE = 0.09, $p = 0.013$) and a smaller direct effect on shooting accuracy ($\beta = -0.16$, SE = 0.01, $p < 0.001$). The full model explained 37% of the variance in shooting accuracy ($R^2 = 0.37$) and 31% of the variance in performance stability ($R^2 = 0.31$).

Overall, the findings indicate that competitive state anxiety plays a central mediating role linking dispositional anxiety tendencies to objective performance outcomes. Elevated anxiety was associated with greater shot-to-shot variability and reduced accuracy, supporting theoretical predictions from multidimensional anxiety and attentional control frameworks. These results highlight the importance of psychological regulation strategies aimed at reducing situational anxiety and enhancing performance stability in precision sport contexts.

Keywords: Competitive anxiety, shooting accuracy, performance stability, archery performance, structural equation modeling, university athletes.

Relevance to Ergonomics: From the perspective of ergonomics, the findings of this study could provide evidence on how psychological factors, particularly competitive

anxiety, influence fine motor control and performance stability in high-precision tasks. Contemporary ergonomics not only examines the physical interaction between humans and work systems, but also the cognitive and emotional interactions that can affect efficiency, precision, and safety during task execution. First, the results show that state anxiety is significantly associated with decreased performance stability ($\beta = -0.42$, $p < 0.001$) and shooting accuracy ($\beta = -0.31$, $p = 0.002$). From an ergonomic perspective, this suggests that emotional states can alter neuromuscular coordination, force regulation, and postural control, factors that are critical in activities requiring highly controlled repetitive movements. These findings reinforce the importance of considering psychophysiological variables in the ergonomic design of tasks that demand precision.

Second, the finding that performance stability significantly predicts shooting accuracy ($\beta = 0.56$, $p < 0.001$) indicates that motor consistency is a key component of human performance in human-machine systems. In applied ergonomics, this type of evidence can contribute to the design of work environments, interfaces, and tools that minimize cognitive and emotional load, allowing operators to maintain optimal motor control and sustained attention.

Furthermore, the structural model showed that trait anxiety influences performance indirectly through state anxiety. This implies that individual characteristics of the operator should be considered in ergonomic analyses. In industrial or technological contexts that require high levels of precision, such as surgical procedures, industrial process control, or manipulation of high-accuracy instruments, stress and anxiety management may be just as important as the physical design of the system.

Finally, these results provide useful evidence for the development of integrated ergonomic interventions, which include not only optimization of the physical environment and work tools but also emotional regulation strategies, attentional training, and psychological preparation. Integrating these elements can help improve efficiency, reduce human error, and enhance performance stability in critical precision-based tasks.

1. INTRODUCTION

Archery is a precision sport in which performance success depends on the athlete's ability to execute highly refined motor actions under conditions of psychological pressure (Tokmakci et al., 2023). Unlike sports characterized by dynamic and reactive movement patterns, archery requires sustained postural stability, fine motor control, attentional focus, and precise temporal coordination throughout the shooting sequence (Wang et al., 2022). Minor disturbances in cognitive or emotional state can disrupt motor execution and lead to measurable decrements in shooting accuracy (Tokmakci et al., 2023).

Competitive anxiety has been widely recognized as a critical psychological factor influencing performance in sport (Ford et al., 2017). Within the multidimensional framework of anxiety, researchers distinguish between state anxiety, a transient emotional response to situational demands, and trait anxiety, a stable personality

disposition reflecting a general tendency to perceive competitive situations as threatening (Zhao et al., 2024). Although both dimensions have been associated with performance outcomes, their relative influence appears to vary depending on task demands and the precision required (Ford et al., 2017).

In precision-based sports such as archery, anxiety may affect performance through increased muscle tension, altered breathing patterns, impaired attentional control, and disrupted motor timing (Li and Wang, 2025). Elevated state anxiety has been linked to reductions in movement smoothness and increased motor variability, both of which are critical determinants of shooting accuracy (Li and Wang, 2025). Trait anxiety, by contrast, may influence long-term performance consistency by shaping habitual responses to stress, affecting confidence, coping strategies, and attentional regulation (Niering et al., 2023).

Several theoretical perspectives provide explanatory frameworks for understanding anxiety-performance relationships. Multidimensional Anxiety Theory suggests that cognitive and somatic anxiety have distinct effects on performance, while Attentional Control Theory proposes that anxiety reduces processing efficiency by diverting attentional resources toward threat-related stimuli (Niering et al., 2023). Catastrophe Theory further suggests that performance may deteriorate rapidly when cognitive anxiety interacts with excessive physiological arousal (Hardy and Parfitt, 1991). Despite these models, empirical findings in archery remain mixed, partly due to methodological variability and limited sample sizes (Ford et al., 2017).

Although interest in psychological determinants of precision sport performance has increased, few studies have directly compared the effects of state and trait anxiety on objective archery performance indicators (Kaur and Shenoy, 2019). Existing research often relies on self-reported perceptions rather than quantifiable outcomes such as accuracy scores or performance variability under competitive conditions. Consequently, the specific pathways through which different anxiety dimensions influence archery performance remain insufficiently understood.

1. OBJECTIVES

Building upon multidimensional and attentional control frameworks (Hardy & Parfitt, 1991; Eysenck et al., 2007), the present study sought to examine the anxiety-performance relationship in university archers using a multivariate and multilevel analytical approach.

General objective

To model the multidimensional and potentially nonlinear relationships between competitive state anxiety, trait anxiety, and objective shooting performance (accuracy and variability) in university archers under simulated competitive conditions.

Specific objectives

- a) To examine the differential contributions of cognitive and somatic components of state anxiety to shooting accuracy and performance variability.
- b) To test whether trait anxiety indirectly influences shooting accuracy through its effect on state anxiety (mediation model).

- c) To evaluate whether state anxiety moderates the relationship between trait anxiety and performance outcomes.
- d) To investigate potential nonlinear (curvilinear or catastrophe-type) relationships between anxiety and shooting accuracy.
- e) To assess within-athlete shot-to-shot variability using multilevel modeling to distinguish between intra-individual and inter-individual performance fluctuations.
- f) To compare predictive models (linear, nonlinear, and structural equation models) to determine the most parsimonious explanation of anxiety-performance dynamics.

2. METHODOLOGY

2.1 Study design

A cross-sectional, correlational research design was employed to examine the complex relationships between competitive anxiety dimensions and shooting performance in university archers. Although the study did not involve experimental manipulation, it incorporated advanced analytical strategies, including multilevel modeling and structural equation modeling (SEM), to capture both between-athlete differences and within-athlete performance fluctuations. This design allowed for the simultaneous examination of direct, indirect, and nonlinear effects while maintaining ecological validity under competition-like conditions.

The theoretical foundation of the study integrated three complementary frameworks. First, Multidimensional Anxiety Theory proposed by Martens et al. (1990) provided the basis for distinguishing between cognitive anxiety (worry and negative expectations), somatic anxiety (physiological arousal), and self-confidence. This perspective assumes that anxiety is not a unitary construct and that its cognitive and physiological components may exert differential effects on performance outcomes. Within precision sports such as archery, cognitive anxiety is expected to interfere with attentional focus and decision processes, whereas somatic anxiety may influence motor control through increased muscular tension and altered neuromuscular coordination.

Second, the study incorporated Attentional Control Theory developed by Eysenck et al. (2007), which posits that anxiety impairs processing efficiency by reallocating attentional resources toward threat-related stimuli. According to this framework, heightened state anxiety reduces the efficiency of the goal-directed attentional system while increasing the influence of stimulus-driven processes. In the context of archery, such attentional disruptions may manifest as decreased shot consistency, reduced fine motor precision, and increased performance variability. This theoretical lens supports modeling performance stability as a mediating mechanism linking anxiety to shooting accuracy.

Third, the model was informed by Catastrophe Theory of Anxiety and Performance advanced by Hardy and Parfitt (1991), which suggests that performance does not always decline linearly with increasing anxiety. Instead, when cognitive anxiety interacts with elevated physiological arousal, performance may

deteriorate abruptly after a critical threshold is reached. This perspective justifies the inclusion of nonlinear (quadratic) effects and latent interaction terms within the structural model to test for potential inverted-U or discontinuous performance patterns under competitive pressure.

Methodologically, the analytical framework combined several complementary statistical techniques. Initial correlational analyses were used to identify basic associations between trait anxiety, state anxiety components, shooting accuracy, and performance variability. Regression-based approaches were then employed to estimate direct predictive effects and to test mediation and moderation hypotheses. Because shooting data were nested (multiple shots within each athlete), multilevel modeling was implemented to partition variance into within-athlete and between-athlete components, allowing for a more precise estimation of performance stability under pressure. Finally, structural equation modeling (SEM) was used to test the integrated theoretical model, enabling simultaneous estimation of measurement and structural pathways, assessment of latent constructs, and comparison of competing models. This multivariate and hierarchical strategy provided a rigorous framework for evaluating both linear and nonlinear anxiety-performance dynamics in precision sport contexts.

2.2 Participants

The sample consisted of sixty-five competitive university archers (37 males and 28 females) aged between 18 and 25 years (Mean = 21.4, SD = 1.9), recruited from established collegiate archery programs. Participants were actively engaged in structured training and interuniversity competition at the time of data collection, ensuring ecological validity in relation to competitive demands. The age range was selected to reflect the typical developmental stage of university-level athletes, characterized by consolidated motor skill acquisition and increasing exposure to performance pressure.

To ensure sample homogeneity in competitive experience and skill level, specific inclusion criteria were applied. Eligible participants (figure 1) were required to have a minimum of one year of competitive formal experience in archery, to be currently engaged in systematic training at least three times per week, and to have participated in at least one officially sanctioned competition within the previous 12 months.

These criteria were established to ensure that participants possessed sufficient exposure to competitive stressors and performance evaluation contexts, thereby making the assessment of competitive anxiety theoretically and practically meaningful.

A priori statistical power analysis was conducted using G*Power 3.1 to determine the minimum required sample size for detecting medium effect sizes in correlational and regression-based analyses. Based on conventional benchmarks ($\rho = 0.30$; $f^2 = 0.15$), with statistical power set at 0.80 and alpha at 0.05, the recommended minimum sample size was 62 participants. The final sample of 65 archers therefore exceeded this requirement, providing adequate statistical sensitivity to detect theoretically relevant associations and structural pathways within

the proposed analytical framework, including multilevel and structural equation modeling components.

All procedures complied with ethical standards for research involving human participants. Ethical approval was obtained from the corresponding institutional review board, and the study adhered to the principles outlined in the World Medical Association's Declaration of Helsinki. Prior to participation, all athletes provided informed consent after receiving detailed information regarding the study's purpose, procedures, confidentiality safeguards, and voluntary nature of participation. Participants were informed of their right to withdraw from the study at any time without penalty.

2.3 Instruments

2.3.1 State anxiety

Competitive state anxiety was measured using the Competitive State Anxiety Inventory-2 (CSAI-2), a widely used instrument grounded in the principles of Multidimensional Anxiety Theory. The scale was developed to assess athletes' immediate emotional and physiological responses in competitive contexts and has been extensively validated across a wide range of sport populations. The CSAI-2 evaluates three theoretically distinct components of pre-competitive anxiety: cognitive anxiety, somatic anxiety, and self-confidence.

The cognitive anxiety subscale reflects mental components of anxiety, including worry, negative expectations, intrusive thoughts, and concerns about potential performance failure. These cognitive processes may disrupt attentional focus and interfere with decision-making and motor planning during performance. The somatic anxiety subscale captures physiological manifestations of anxiety such as increased muscle tension, elevated heart rate, sweating, and sensations commonly described by athletes as "butterflies in the stomach." These physiological responses are associated with autonomic nervous system activation and may influence motor coordination and movement stability.

The third dimension, self-confidence, reflects an athlete's belief in their ability to perform successfully and is conceptualized as a protective psychological factor that can counteract the negative effects of anxiety.

Participants responded to CSAI-2 items using a Likert-type scale that measures the intensity of each symptom at the present moment. This time-specific format makes the instrument particularly suitable for assessing situational anxiety immediately before performance tasks. In the present study, the CSAI-2 was administered directly prior to the shooting task to capture anticipatory emotional states under competition-like conditions.

Internal consistency reliability for the instrument was evaluated using Cronbach's alpha coefficients. Results indicated satisfactory reliability for all subscales within the present sample of university archers: cognitive anxiety ($\alpha = 0.86$), somatic anxiety ($\alpha = 0.82$), and self-confidence ($\alpha = 0.88$). These values exceed the commonly accepted reliability threshold of $\alpha \geq 0.70$, indicating strong internal coherence among scale items.

Within the structural equation modeling framework used in this study, cognitive anxiety and somatic anxiety were specified as first-order observed indicators contributing to a higher-order latent construct representing state competitive anxiety. In contrast, self-confidence was modeled as a theoretically related but distinct construct, consistent with multidimensional conceptualizations of competitive emotional states in sport psychology research. This specification allowed the analysis to examine both the combined influence of situational anxiety and the potentially buffering role of self-confidence on archery performance outcomes.

2.3.2 Trait anxiety

Trait competitive anxiety was assessed using the Sport Competition Anxiety Test (SCAT), originally developed by Rainer Martens, Robin S. Vealey, and Damon Burton (1990). The SCAT is a standardized psychometric instrument designed to measure relatively stable individual differences in athletes' tendency to perceive competitive situations as threatening and to respond with elevated anxiety. Within the framework of sport psychology, trait anxiety represents a dispositional characteristic that influences how individuals interpret and react to competitive stressors over time.

Unlike state-based measures, which capture temporary emotional reactions in specific situations, the SCAT focuses on enduring psychological tendencies associated with competition. The instrument evaluates habitual emotional responses that athletes typically experience before or during competitive events, including worry about performance outcomes, concerns about evaluation by others, and general feelings of nervousness in competitive settings. These dispositional patterns are considered important predictors of situational anxiety responses, as individuals with higher trait anxiety are more likely to interpret competitive environments as stressful and to experience heightened emotional arousal.

The SCAT consists of a series of statements describing common competitive reactions, to which participants respond using a structured Likert-type scale reflecting the frequency or intensity of each experience. Items are designed to capture consistent emotional patterns rather than momentary feelings, thereby providing an index of long-term competitive anxiety predisposition.

In the present sample, the SCAT demonstrated satisfactory internal consistency reliability, with Cronbach's alpha coefficient of $\alpha = 0.84$. This value exceeds the commonly accepted threshold for acceptable reliability ($\alpha \geq 0.70$), indicating that the instrument provides a stable and coherent measure of trait competitive anxiety within the population of university archers examined in this study.

Within the analytical framework, trait anxiety was specified as an exogenous observed variable in the structural model. This specification reflects theoretical assumptions that stable personality dispositions influence situational emotional responses, particularly under competitive conditions. Accordingly, trait anxiety was modeled as a predictor of state anxiety components as well as performance-related outcomes, allowing the analysis to examine both direct and indirect pathways linking enduring psychological tendencies to archery performance.

2.3.3 Performance measures

Objective performance indicators were derived from standardized shooting tasks conducted under controlled, competition-simulated conditions. Performance was operationalized using multiple complementary indices to capture both outcome effectiveness and motor consistency.

First, mean shooting accuracy was calculated as the total score obtained across 30 arrows, providing a global indicator of performance effectiveness. This measure reflects the primary competitive objective in archery: maximizing target precision.

Second, within-series performance variability was computed as the standard deviation (SD) of shot scores within each shooting series. This index captures fluctuations in execution and reflects motor consistency under pressure.

Third, the coefficient of variation (CV) was calculated by dividing the standard deviation by the mean score and multiplying by 100, thereby standardizing variability relative to individual performance levels. The CV provides a normalized indicator of stability, allowing comparison across athletes with differing accuracy levels.

Fourth, for multilevel modeling purposes, shot-level deviation from the individual mean was computed for each arrow. This metric enabled the analysis of within-athlete variability across repeated shots, facilitating hierarchical linear modeling that partitions performance variance into intra-individual and inter-individual components.

Together, these performance indicators allowed for a multidimensional assessment of archery performance, distinguishing between absolute accuracy and stability of execution, both theoretically distinct but interrelated aspects of precision sport performance.

2.4 Procedure

Data collection was conducted in a controlled indoor archery range to ensure environmental consistency and to approximate official competition conditions. Lighting intensity, ambient temperature, lane spacing, and target distance were standardized for all participants. The shooting distance was fixed at 18 meters, consistent with indoor competitive regulations, thereby enhancing ecological validity while maintaining experimental control. External distractions were minimized, and all sessions were scheduled at similar times of day to reduce potential circadian influences on performance and psychological state.

The procedural sequence followed a structured protocol. Upon arrival, participants first completed the Sport Competition Anxiety Test (SCAT) to assess baseline trait competitive anxiety. This assessment was administered in a quiet area adjacent to the range to avoid situational arousal effects prior to measurement. Participants were then given a standardized 15-minute warm-up period, which included light stretching, mobility exercises, and practice shots. The warm-up protocol was uniform across athletes to control preparatory variability that might influence performance outcomes.

Following the warm-up and prior to the commencement of the scored shooting task, participants completed the Competitive State Anxiety Inventory-2 (CSAI-2). This timing ensured that state anxiety levels reflected anticipatory competitive stress

rather than post-performance reactions. The administration was conducted individually to prevent social influence or peer comparison effects.

Participants then completed a standardized shooting task consisting of 30 arrows divided into three series of 10 shots each, replicating a formal competition format (Figure 1). Brief rest intervals were provided between series to simulate official event pacing while minimizing fatigue effects. All shots were scored according to official target scoring criteria, and each arrow score was recorded individually. Recording shot-level data allowed for subsequent hierarchical (multilevel) modeling to partition within-athlete variability from between-athlete performance differences.



Figure 1. Competitive university archer performing a standardized shooting attempt during a regulation-distance target archery task used for accuracy assessment.

To preserve ecological validity and ensure authentic motor execution patterns, athletes used their personal bows, arrows, and accessories. Equipment inspection confirmed compliance with standard competitive specifications. No technical feedback was provided during the task, and communication was limited to procedural instructions to avoid influencing attentional focus or emotional state. This structured and standardized procedure ensured methodological rigor while maintaining a performance environment representative of real competitive conditions.

2.5 Data analysis

2.5.1 Preliminary analyses

Prior to hypothesis testing, a comprehensive data screening procedure was conducted to ensure statistical validity and model robustness. All analyses were

performed using IBM SPSS Statistics and IBM SPSS AMOS version 29 (IBM Corp., Armonk, NY, USA), following recommended best practices for multivariate research.

First, missing data patterns were evaluated using Little's Missing Completely at Random (MCAR) test. This procedure determines whether the probability of missingness is unrelated to observed or unobserved data. A non-significant MCAR result supports the assumption that missing values occur randomly, justifying the use of Full Information Maximum Likelihood (FIML) estimation within structural modeling. In cases where minimal missingness (<5%) was detected, expectation-maximization procedures were applied to preserve statistical power and reduce bias.

Second, multivariate outliers were examined using Mahalanobis distance (D^2). This statistic identifies cases with unusual combinations of variable scores relative to the multivariate centroid. Observations exceeding the critical χ^2 threshold ($p < 0.001$, df = number of predictors) were carefully inspected. Rather than automatically removing outliers, cases were evaluated for data entry errors, response inconsistencies, or theoretically meaningful extreme performance under pressure. Decisions regarding exclusion were based on methodological justification and transparency.

Third, distributional assumptions were assessed. Univariate normality was examined using Shapiro-Wilk tests, along with skewness and kurtosis coefficients. Because Shapiro-Wilk is sensitive to moderate sample sizes, graphical diagnostics, including Q-Q plots and histogram inspection, were also used to evaluate distributional shape. Multivariate normality was further assessed through Mardia's coefficient where applicable. Results indicated mild deviations from normality, particularly for performance variability indices, which is common in sport performance data.

Fourth, multicollinearity diagnostics were conducted to evaluate potential redundancy among predictors. Variance Inflation Factor (VIF) values were calculated in regression analyses, with thresholds of $VIF < 5$ indicating acceptable independence among predictors. Tolerance values (> 0.20) were also examined to ensure stability of parameter estimates in subsequent structural modeling.

Given the presence of mild non-normality, robust maximum likelihood estimation (MLR) was applied in structural equation modeling procedures. MLR provides standard errors and chi-square statistics that are robust to non-normality, thereby improving the accuracy of parameter estimates and model fit indices. This approach enhances the reliability of inferences drawn from complex multivariate models, particularly when testing mediation, moderation, and nonlinear effects within anxiety-performance dynamics.

2.5.2 Correlational and nonlinear modeling

Initial analyses examined bivariate associations among trait anxiety, state anxiety components (cognitive and somatic), self-confidence, shooting accuracy, and performance variability using Spearman's rank-order correlation coefficients (ρ). Spearman correlations were selected due to mild deviations from normality and the ordinal properties of some psychological scale data. Effect sizes were interpreted according to conventional benchmarks ($\rho \approx 0.10$ small, 0.30 medium, 0.50 large),

with two-tailed significance set at $\alpha = 0.05$. These analyses provided a preliminary assessment of the strength and direction of associations prior to multivariate modeling.

To evaluate potential nonlinear relationships between anxiety and performance, particularly those predicted in high-pressure precision sports, hierarchical regression analyses were conducted. In Step 1, linear terms for anxiety (trait and state components) were entered as predictors of shooting accuracy and performance stability. In Step 2, quadratic terms (anxiety²) were added after centering the predictor variables to reduce multicollinearity between linear and squared terms. A statistically significant quadratic coefficient (β_2) accompanied by a meaningful increase in explained variance (ΔR^2) was interpreted as evidence of curvilinear effects, such as inverted-U or threshold patterns.

To further probe possible discontinuities in performance, piecewise (segmented) regression models were estimated. This approach allows separate linear slopes to be calculated for lower versus higher levels of anxiety, with a breakpoint determined either theoretically (e.g., sample median or upper quartile) or empirically through model fit optimization. Piecewise modeling is particularly useful for identifying potential inflection points where performance deterioration accelerates under elevated cognitive anxiety.

Model comparisons between linear and quadratic specifications were conducted using changes in explained variance (ΔR^2) and information criteria (AIC: Akaike Information Criterion; BIC: Bayesian Information Criterion), with lower values indicating better model fit. Improvements in fit for nonlinear models were interpreted as partial empirical support for catastrophe-type dynamics, as proposed by Hardy and Parfitt (1991). Although full catastrophe modeling requires complex bifurcation analysis, the inclusion of quadratic and segmented regression components provided a pragmatic approximate on for detecting nonlinear anxiety-performance patterns within the present sample.

Together, these correlational and nonlinear procedures enabled a rigorous examination of both monotonic and curvilinear relationships, thereby strengthening the analytical depth of the anxiety-performance investigation.

2.5.3 Multilevel Modeling (Hierarchical Linear Modeling)

Because performance data consisted of repeated shots nested within individual athletes, multilevel modeling, also known as Hierarchical Linear Modeling (HLM), was employed to appropriately account for the hierarchical structure of the data. In repeated measures sport performance datasets, observations taken from the same individual are not statistically independent. Ignoring this dependency violates assumptions of conventional regression models and can lead to underestimated standard errors and biased parameter estimates. Multilevel modeling addresses this issue by explicitly modeling variance at different levels of analysis, thereby providing more accurate estimates of relationships among predictors and outcomes (Stephen W. Raudenbush & Anthony S. Bryk, 2002; Joop Hox, 2010).

In the present study, the dataset contained repeated performance observations (individual arrow scores) nested within athletes. Each participant completed a

sequence of 30 arrows during the simulated competition task, generating shot-level observations that were hierarchically structured within individuals. To properly model this nested structure, a two-level multilevel model was specified in which Level 1 represented within-athlete variability and Level 2 represented between-athlete differences.

At Level 1 (within-athlete level), the model examined fluctuations in shot accuracy across the sequence of arrows for each athlete. Shot-level deviation from the individual mean score was modeled as a function of shot order to capture potential trends related to fatigue, attentional drift, or pressure accumulation throughout the shooting task. The Level 1 model was specified (Equation 1) as:

$$\text{Shot Accuracy Deviation}_{ij} = \beta_{0j} + \beta_{1j} (\text{Shot Number}_{ij}) + r_{ij} \quad (1)$$

In this equation, Shot Accuracy Deviation_{ij} represents the deviation of shot *i* for athlete *j* relative to that athlete's average score. The intercept β_{0j} represents the expected mean performance level for athlete *j*, while β_{1j} represents the slope associated with the shot number variable, capturing potential systematic performance changes across the shooting sequence. The residual term r_{ij} represents unexplained within-athlete variability.

At Level 2 (between-athlete level), athlete-specific intercepts from the Level 1 model were modeled as a function of psychological predictors reflecting individual differences in competitive anxiety. The Level 2 equation was specified (Equation 2) as:

$$\beta_{0j} = \gamma_{00} + \gamma_{01} (\text{State Anxiety}_j) + \gamma_{02} (\text{Trait Anxiety}_j) + u_{0j} \quad (2)$$

In this specification, γ_{00} represents the grand mean performance level across all athletes, while γ_{01} and γ_{02} represent the fixed effects of state anxiety and trait anxiety, respectively, on mean shooting performance. The term u_{0j} represents the random effect associated with each athlete, capturing unexplained between-athlete variability not accounted for by the psychological predictors. Modeling psychological variables at Level 2 allows examination of whether athletes with higher anxiety levels exhibit systematically different performance patterns compared with those with lower anxiety levels.

Prior to estimating the full multilevel model, an unconditional (null) model without predictors was estimated to quantify the proportion of variance attributable to each level of the hierarchy. From this model, the Intraclass Correlation Coefficient (ICC) was calculated. The ICC represents the proportion of total variance in shot accuracy that can be attributed to stable differences between athletes rather than moment-to-moment variability within athletes (Snijders and Bosker, 2012). A non-zero ICC indicates meaningful clustering of observations within individuals and provides statistical justification for the use of multilevel modeling.

The multilevel framework offers important analytical advantages in the study of precision sport performance. First, it allows simultaneous examination of between-athlete performance differences, reflecting stable skill and psychological characteristics, and within-athlete performance instability, which may emerge as athletes experience fluctuating attentional control, emotional arousal, or pressure

during the shooting sequence. Second, by incorporating psychological predictors at the appropriate level of analysis, the model provides a more nuanced understanding of how competitive anxiety influences both average performance and shot-by-shot variability. Such hierarchical approaches have become increasingly recommended in sport psychology and performance science research involving repeated performance measures (Raudenbush and Bryk, 2002; Hox, 2010).

2.5.4 Mediation and moderation analyses

To further examine the underlying mechanisms linking competitive anxiety to shooting performance, mediation and moderation analyses were conducted using regression-based path modeling procedures equivalent to process macro-Model 4 (simple mediation) and Model 1 (simple moderation) as developed by Hayes (2018). These analyses allowed for the decomposition of direct, indirect, and interaction effects while complementing the structural equation modeling framework described previously.

For the mediation analysis, trait anxiety was specified as the independent variable (X), state anxiety as the mediator (M), and shooting accuracy as the dependent variable (Y). This model tested the hypothesis that stable competitive anxiety predispositions influence performance indirectly through situational emotional responses immediately prior to shooting. The total effect (c path), direct effect (c' path), and indirect effect ($a \times b$ path) were estimated. A statistically significant indirect pathway was interpreted as evidence that state anxiety partially or fully mediates the relationship between trait anxiety and performance outcomes. Parallel mediation models were also explored to distinguish the specific contributions of cognitive and somatic state anxiety components.

Moderation analysis examined whether the effect of trait anxiety on shooting accuracy varied as a function of state anxiety levels. An interaction term (Trait Anxiety $\times$ State Anxiety) was computed after mean-centering predictor variables to reduce multicollinearity. A significant interaction coefficient (β_3) indicated that the relationship between trait anxiety and performance differed depending on situational anxiety intensity. When significant, simple slopes analyses were conducted at low (-1 SD), mean, and high ($+1$ SD) levels of the moderator to facilitate interpretation.

All indirect effects were tested using nonparametric bootstrapping with 5,000 resamples to generate bias-corrected 95% confidence intervals. Bootstrapping does not rely on the assumption of normality of the indirect effect distribution and is therefore recommended for mediation analysis in psychological research. An indirect effect was considered statistically significant when the confidence interval did not include zero. Together, these mediation and moderation procedures provided a more nuanced understanding of how stable anxiety tendencies translate into situational responses and how these dynamic processes influence objective archery performance under competitive conditions.

2.5.5 Structural Equation Modeling

To examine the relationships between psychological variables and performance outcomes, Structural Equation Modeling (SEM) was employed following the SEM framework (Figure 1). SEM is a multivariate statistical technique that integrates elements of factor analysis and multiple regression, allowing researchers to simultaneously estimate relationships among observed variables and latent constructs while accounting for measurement error. This approach is particularly suitable for testing theoretically grounded models involving psychological constructs such as anxiety and performance, which cannot be directly observed and must be represented through multiple indicators (Kline, 2016; Barbara M. Byrne, 2016).

In the present study, SEM was used to evaluate a conceptual model linking trait anxiety, state anxiety, and sport performance. Trait anxiety was included as an observed exogenous variable, reflecting a stable individual predisposition to perceive competitive situations as threatening. In contrast, state anxiety was modeled as a latent construct represented by multiple observed indicators capturing its cognitive and somatic dimensions. This modeling strategy follows theoretical frameworks suggesting that competitive anxiety is a multidimensional construct composed of both cognitive components (e.g., worry, negative expectations) and physiological or somatic components (e.g., tension, increased arousal) (Martens et al., 1990).

The latent state anxiety factor was specified using indicators derived from validated measures of competitive anxiety that capture both cognitive and somatic symptoms experienced immediately before or during performance situations. Modeling these indicators as reflective measures allows the latent variable to represent the underlying psychological construct while reducing measurement error associated with individual questionnaire items.

Performance was also represented as a latent factor, constructed from two complementary observed indicators: shot accuracy and inverse performance variability. Shot accuracy reflects the degree to which each attempt approaches the intended target, whereas inverse variability represents performance consistency across repeated attempts. Combining these indicators into a latent performance construct provides a more comprehensive representation of performance quality by capturing both precision and stability across trials.

The structural portion of the model specified directional relationships among variables consistent with theoretical assumptions in sport psychology. Trait anxiety was hypothesized to influence state anxiety levels, reflecting the notion that individuals with higher dispositional anxiety are more likely to experience heightened situational anxiety in competitive contexts. State anxiety, in turn, was modeled as a predictor of the latent performance factor, allowing the analysis to evaluate the extent to which momentary anxiety responses influence task execution under competitive pressure.

Model estimation was conducted using maximum likelihood procedures, which provide efficient and unbiased parameter estimates under conditions of multivariate normality (Kline, 2016). Model adequacy was evaluated using multiple goodness-of-fit indices, reflecting recommended best practices for SEM reporting (Hu and Bentler,

1999). Specifically, the following criteria were used to assess model fit: Comparative Fit Index (CFI) ≥ 0.95 , Tucker–Lewis Index (TLI) ≥ 0.95 , Root Mean Square Error of Approximation (RMSEA) ≤ 0.06 , and the Standardized Root Mean Square Residual (SRMR) ≤ 0.08 .

These indices evaluate complementary aspects of model performance, including incremental fit relative to a null model, parsimony-adjusted fit, and residual-based discrepancies between observed and model-implied covariance matrices.

To determine the relative adequacy of competing theoretical specifications, model comparison procedures were also conducted using the AIC and BIC. These indices balance model fit with model complexity, penalizing unnecessary parameters and allowing the identification of the most parsimonious model that adequately explains the observed data. Lower AIC and BIC values indicate a preferable balance between explanatory power and parsimony.

Overall, the SEM framework enabled a comprehensive evaluation of the hypothesized relationships among stable anxiety predispositions, situational anxiety responses, and performance outcomes within a unified analytical model, consistent with contemporary methodological approaches in sport and performance psychology research

The proposed conceptual model (Figure 2) is grounded in three complementary theoretical frameworks that explain how anxiety influences performance in competitive contexts: Multidimensional Anxiety Theory, Attentional Control Theory, and the Catastrophe Theory of Anxiety and Performance. Together, these perspectives provide a comprehensive framework for understanding the cognitive, emotional, and performance-related mechanisms involved in competitive anxiety.

First, Multidimensional Anxiety Theory, developed by Rainer Martens, Robin S. Vealey, and Damon Burton, proposes that competitive anxiety consists of distinct but related components, primarily cognitive anxiety and somatic anxiety. Cognitive anxiety refers to negative expectations, worries, and concerns about performance outcomes, whereas somatic anxiety reflects physiological arousal such as muscle tension, increased heart rate, and autonomic activation.

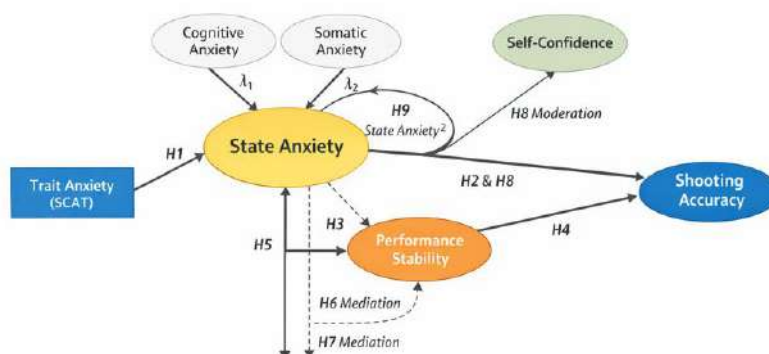


Figure 2. Structural Equation Model of competitive anxiety and shooting performance in university archers.

According to this framework, these dimensions influence athletic performance through different mechanisms and may follow different temporal patterns before and during competition. Multidimensional Anxiety Theory also suggests that athletes with higher levels of trait anxiety are more likely to experience elevated state anxiety in competitive situations, highlighting the interaction between stable psychological predispositions and situational responses (Martens et al., 1990).

Second, Attentional Control Theory, proposed by Michael W. Eysenck et al. (2007) provides a cognitive explanation for how anxiety affects performance. The theory posits that anxiety disrupts the efficiency of the attentional control system, particularly the balance between goal-directed (top-down) and stimulus-driven (bottom-up) attentional processes. Under conditions of elevated anxiety, individuals' experience reduced attentional control, leading to increased susceptibility to task-irrelevant stimuli, intrusive thoughts, and performance-related worries. As a result, cognitive resources that would normally support task execution become partially diverted, potentially impairing accuracy, consistency, and decision-making during performance tasks (Eysenck et al., 2007).

Third, the Catastrophe Theory of Anxiety and Performance, developed by Lew Hardy and Graham Parfitt, introduces a nonlinear perspective on the relationship between anxiety and performance. According to this theory, performance outcomes are influenced by the interaction between physiological arousal and cognitive anxiety. When cognitive anxiety is low, increases in physiological arousal may enhance performance up to an optimal point, consistent with classical arousal-performance models. However, when cognitive anxiety is high, further increases in physiological arousal can trigger a sudden and dramatic decline in performance, referred to as a catastrophic drop. This nonlinear dynamic suggests that performance instability may emerge under high-pressure conditions, particularly when both cognitive anxiety and physiological activation reach elevated levels (Hardy and Parfitt, 1991).

By integrating these three frameworks, the present conceptual model proposes that competitive anxiety influences performance through both direct and indirect mechanisms. Trait anxiety contributes to the development of state anxiety in competitive situations, while state anxiety affects performance through attentional control processes and physiological activation. Additionally, the model acknowledges the possibility that anxiety-performance relationships may not always follow simple linear patterns, particularly under conditions of heightened pressure or arousal.

This integrative theoretical foundation provides the basis for the structural relationships examined in the subsequent empirical model, linking stable anxiety predispositions, situational anxiety responses, and objective performance indicators within a unified analytical framework.

Latent variable structure

The SEM developed for this study specifies four primary constructs that represent the psychological and performance-related mechanisms involved in competitive archery. These constructs include trait competitive anxiety, state anxiety, performance stability, and shooting accuracy, organized within a

theoretically driven framework that distinguishes between stable predispositions, situational emotional responses, and objective performance outcomes.

First, trait competitive anxiety is modeled as an observed exogenous variable representing athletes' stable predisposition to perceive competitive environments as threatening or stressful. This construct was measured using the Sport Competition Anxiety Test (SCAT), developed by Martens et al. (1990). The total SCAT score was used as the observed indicator of trait anxiety. Within the structural model, trait anxiety functions as a distal psychological characteristic that influences situational emotional responses and may indirectly affect performance outcomes through its relationship with state anxiety processes.

Second, state anxiety is specified as a latent endogenous construct reflecting athletes' immediate emotional responses to competitive pressure. This latent variable is conceptualized as a higher-order factor composed of two first-order indicators derived from the Competitive State Anxiety Inventory-2 (CSAI-2), developed by Martens et al. (1990). The first indicator, cognitive anxiety, captures mental components such as worry, performance concerns, and negative expectations about outcomes. The second indicator, somatic anxiety, represents physiological activation associated with competitive stress, including perceived tension, autonomic arousal, and bodily symptoms of anxiety. In this modeling framework, self-confidence, also measured by the CSAI-2, is not incorporated into the latent anxiety construct but instead treated as a theoretically related yet distinct psychological variable that may correlate with the anxiety dimensions without constituting part of the same latent factor.

Third, performance stability is conceptualized as a latent endogenous construct representing the degree of motor consistency and control during the shooting task. Rather than focusing solely on overall accuracy, this construct captures the variability of performance across repeated shots, reflecting the athlete's ability to maintain consistent execution under pressure. The latent variable is indicated by three performance-derived metrics: inverse performance variability (the negative standard deviation of shot scores), inverse coefficient of variation, and aggregated shot-to-shot deviation residuals derived from within-athlete performance modeling. These indicators specify that higher values represent greater performance stability, meaning lower variability and higher consistency in shot execution.

Finally, shooting accuracy is specified as the primary performance outcome variable within the model. This construct may be modeled as either a latent factor or an observed composite variable depending on estimation considerations and model fit. It is represented by three indicators reflecting different aspects of shooting performance: total score obtained across all shots, mean shot score, and final series score, which captures performance during the final phase of the shooting sequence when psychological pressure is typically highest. Including this pressure-sensitive indicator allows the model to account for potential anxiety effects that emerge more strongly during the concluding stages of competition.

Together, these four constructs form a theoretically coherent SEM framework linking stable psychological predispositions, situational emotional responses, and objective performance indicators, enabling the examination of both direct and indirect relationships between competitive anxiety and shooting performance.

Structural pathways

The conceptual model specifies a set of directional structural relationships linking psychological predispositions, situational emotional responses, and performance outcomes. First, trait competitive anxiety is hypothesized to predict state anxiety, reflecting the theoretical assumption that stable anxiety tendencies influence athletes' emotional reactions immediately prior to competition. Second, state anxiety is modeled as a direct predictor of shooting accuracy, based on theoretical perspectives suggesting that elevated anxiety can impair fine motor control and attentional focus during precision tasks. Third, state anxiety is also expected to influence performance stability, representing the degree of shot-to-shot motor consistency during the shooting sequence.

In addition to these indirect pathways, trait anxiety is specified as having a direct effect on performance stability, acknowledging the possibility that dispositional anxiety influences motor consistency independently of momentary emotional states. Performance stability, in turn, is hypothesized to predict shooting accuracy, reflecting the assumption that greater motor consistency contributes to higher overall scoring performance. The model further includes both direct and indirect pathways from trait anxiety to shooting accuracy, allowing the analysis to test whether the influence of dispositional anxiety on performance occurs partially through situational anxiety processes and performance stability mechanisms.

To examine potential nonlinear effects consistent with theoretical models of anxiety–performance relationships, a quadratic path from state anxiety to shooting accuracy is included. This specification allows the model to capture possible curvilinear dynamics in which moderate levels of anxiety may facilitate performance whereas excessive anxiety may produce performance deterioration.

Finally, covariance paths are specified between the cognitive and somatic anxiety indicators, acknowledging their theoretical interdependence within multidimensional models of competitive anxiety, and between state anxiety and self-confidence, reflecting the conceptual relationship between negative emotional arousal and perceived performance readiness. These covariance parameters allow the model to account for shared variance among psychologically related constructs while preserving their conceptual distinctiveness within the structural framework.

2.5.6 Mediation and moderation components

The structural model incorporates both mediation and moderation mechanisms to provide a more comprehensive explanation of how competitive anxiety influences performance in archery. First, a mediation pathway is specified in which trait anxiety predicts state anxiety, which subsequently affects performance outcomes. This mediated relationship reflects the theoretical proposition that stable psychological dispositions influence athletes' momentary emotional responses in competitive contexts, and that these situational responses ultimately affect motor execution and performance effectiveness. Within this framework, state anxiety functions as an intermediate process through which trait anxiety exerts its influence on both shooting accuracy and performance stability.

In addition to mediation, the model includes a moderation component in which self-confidence moderates the relationship between state anxiety and shooting accuracy. Self-confidence is conceptualized as a psychological resource that may buffer the potentially detrimental effects of anxiety on performance. Athletes with higher levels of perceived confidence may be better able to maintain attentional control and motor coordination even under elevated anxiety, whereas those with lower confidence may experience stronger performance impairments. Modeling this interaction allows the analysis to examine whether the impact of state anxiety on shooting performance varies as a function of athletes perceived readiness and belief in successful execution.

Finally, the conceptual framework incorporates a nonlinear component designed to capture potential curvilinear dynamics in the anxiety–performance relationship. Specifically, a quadratic latent interaction term involving state anxiety is introduced to test patterns consistent with inverted-U relationships or catastrophe-type performance effects, in which moderate levels of arousal may facilitate performance but excessive anxiety may produce abrupt performance declines. Including this nonlinear specification enables the structural model to evaluate more complex performance dynamics that may occur in high-precision sports such as archery, where small disruptions in cognitive or physiological regulation can significantly affect shooting accuracy.

The model depicts Trait Anxiety as an exogenous predictor influencing State Anxiety, which in turn predicts both Performance Stability and Shooting Accuracy. Performance Stability serves as a mediator between State Anxiety and Accuracy. A direct path from Trait Anxiety to Accuracy is included to test partial mediation. A quadratic pathway from State Anxiety to Accuracy tests nonlinear effects consistent with catastrophe theory. Self-confidence is modeled as a moderating variable buffering the negative impact of State Anxiety on performance. Latent variables are represented by ellipses, observed indicators by rectangles, and standardized path coefficients are displayed along directional arrows.

Hypotheses aligned with SEM

The structural model proposes several direct relationships between psychological and performance variables. **H1:** Trait anxiety will positively predict state anxiety prior to competition, reflecting the influence of stable anxiety predispositions on situational emotional responses. **H2:** State anxiety will negatively predict shooting accuracy, suggesting that higher situational anxiety may impair precision performance. **H3:** State anxiety will negatively predict performance stability, indicating that elevated anxiety may increase shot-to-shot variability. **H4:** Performance stability will positively predict shooting accuracy, as greater motor consistency is expected to support higher scoring outcomes. **H5:** Trait anxiety will negatively predict performance stability, implying that individuals with higher dispositional anxiety may exhibit less consistent performance under competitive conditions.

The model also proposes mediated relationships between anxiety and performance outcomes. **H6:** The relationship between trait anxiety and shooting accuracy will be partially mediated by state anxiety, indicating that stable anxiety predispositions influence performance primarily through their effect on situational

emotional responses. **H7:** The relationship between state anxiety and shooting accuracy will be partially mediated by performance stability, suggesting that anxiety affects performance indirectly by increasing motor variability and reducing shot-to-shot consistency.

The model also includes a moderation and a nonlinear relationship. **H8:** Self-confidence will moderate the relationship between state anxiety and shooting accuracy such that the negative association between anxiety and performance will be weaker among athletes with higher levels of self-confidence. This hypothesis reflects the assumption that confidence may buffer the detrimental effects of anxiety on precision performance.

Additionally, a nonlinear relationship is proposed. **H9:** The association between state anxiety and shooting accuracy will exhibit a significant quadratic component, indicating that the relationship may follow an inverted-U or catastrophe-type pattern in which moderate levels of anxiety are associated with optimal performance, whereas excessive anxiety leads to performance deterioration.

Comparative model hypothesis

The final hypothesis concerns the comparative adequacy of the proposed structural framework. **H10:** The full structural equation model, incorporating mediation pathways and nonlinear components, will demonstrate superior model fit compared with simpler linear-only models. Model adequacy will be evaluated using standard goodness-of-fit indices, including a Comparative Fit Index (CFI) ≥ 0.95 and Root Mean Square Error of Approximation (RMSEA) ≤ 0.06 , indicating that the more comprehensive model provides a better representation of the relationships among anxiety constructs and archery performance outcomes.

Model testing strategy

The proposed hypotheses will be tested through a multistep analytical strategy designed to evaluate both the measurement and structural components of the conceptual model. First, Confirmatory Factor Analysis (CFA) will be conducted to assess the adequacy of the measurement model and to validate the latent constructs representing state anxiety, performance stability, and shooting performance. This step ensures that the observed indicators reliably represent their corresponding theoretical constructs before testing structural relationships.

Following measurement validation, SEM will be applied to examine the direct and indirect relationships among trait anxiety, state anxiety, performance stability, and shooting accuracy. SEM enables simultaneous estimation of multiple pathways, allowing the evaluation of the hypothesized causal structure of the model.

To investigate potential nonlinear dynamics in the anxiety-performance relationship, latent interaction modeling will be used to estimate quadratic effects involving state anxiety. This procedure allows the structural model to test curvilinear relationships consistent with theoretical predictions of inverted-U or catastrophe-type performance patterns.

Indirect effects associated with mediation hypotheses will be evaluated using bootstrapped confidence intervals based on 5,000 resamples, providing robust estimates of mediation effects without assuming normality of the sampling distribution. Finally, the adequacy of competing models will be assessed through model comparison procedures, including differences in chi-square statistics ($\Delta\chi^2$)

and information criteria such as the AIC and Bayesian Information Criterion BIC, which allow the identification of the model that best balances explanatory power and parsimony.

2.5.6 Bayesian supplementary analysis

In addition to the frequentist statistical procedures described above, a Bayesian supplementary analysis was conducted to provide complementary evidence regarding the relationships between anxiety variables and performance outcomes. Bayesian regression modeling was employed to estimate the posterior distributions of the parameters associated with trait anxiety and state anxiety, allowing a probabilistic interpretation of the magnitude and direction of these effects.

This approach offers several advantages for psychological and behavioral research. First, Bayesian estimation allows the quantification of evidence strength by evaluating the probability distribution of parameter values rather than relying solely on null hypothesis significance testing. Second, it reduces dependence on traditional p-value-based inference, which has been widely criticized for its sensitivity to sample size and dichotomous interpretation of statistical results (Gelman et al., 2013; Kruschke and Liddell, 2018). Instead, Bayesian methods estimate the range of plausible parameter values supported by the observed data.

Finally, credible intervals derived from posterior distributions were calculated for the regression coefficients. Unlike frequentist confidence intervals, Bayesian credible intervals provide a direct probabilistic interpretation, indicating the range within which the parameter value is most likely to lie given the observed data and prior assumptions. The inclusion of Bayesian analysis therefore serves as a robustness check, complementing the structural equation and multilevel modeling results by providing an additional inferential framework for evaluating the influence of competitive anxiety on archery performance.

2.5.7 Effect sizes and interpretation

To provide a comprehensive interpretation of the statistical results, multiple effect size indicators were reported alongside significance tests. For correlational analyses, Spearman's rank correlation coefficient (ρ) was used to quantify the strength and direction of associations between anxiety variables and performance measures. In regression-based analyses, Cohen's f^2 was calculated to estimate the magnitude of explained variance attributable to specific predictors within the model. Additionally, standardized beta coefficients (β) were reported to facilitate comparison of the relative contribution of predictors across regression and structural models.

For multilevel analyses, the Intraclass Correlation Coefficient (ICC) was used to quantify the proportion of total variance attributable to differences between athletes versus within-athlete variability across shots. In the Bayesian supplementary analysis, Bayes Factors (BF_{10}) were calculated to quantify the strength of evidence in favor of the alternative hypothesis relative to the null hypothesis, allowing a graded interpretation of evidential support.

Statistical significance was evaluated using an alpha level of .05. However, interpretation emphasized practical and substantive significance, considering the magnitude and theoretical relevance of effect sizes rather than relying solely on dichotomous significance testing. This approach aligns with contemporary recommendations in psychological and behavioral research that encourage reporting effect sizes and confidence intervals to provide a more informative assessment of empirical findings.

3. RESULTS

3.1 Descriptive statistics and correlations

Descriptive statistics for the principal study variables are presented in Table 1. Athletes reported moderate levels of competitive trait anxiety (Mean = 18.74, SD = 4.21) as measured by the SCAT. Pre-performance state anxiety scores obtained from the CSAI-2 indicated moderate cognitive anxiety (Mean = 20.36, SD = 5.12) and somatic anxiety (Mean = 18.91, SD = 4.67), while self-confidence levels were comparatively higher (Mean = 26.44, SD = 5.03).

Shooting performance across all trials showed a mean accuracy score of 8.67 points per shot (SD = 0.74). The standard deviation of shot accuracy within athletes, used as an indicator of performance stability, averaged 0.61 (SD = 0.18). Lower values represented greater motor consistency. Spearman correlation analyses indicated a significant positive association between trait anxiety and state anxiety ($\rho = 0.46$, $p < 0.001$). State anxiety demonstrated a negative correlation with shooting accuracy ($\rho = -0.38$, $p < 0.001$) and performance stability ($\rho = -0.34$, $p = 0.002$).

Performance stability was positively correlated with shooting accuracy ($\rho = 0.55$, $p < 0.001$). Self-confidence was negatively correlated with state anxiety ($\rho = -0.41$, $p < 0.001$) and positively associated with shooting accuracy ($\rho = 0.29$, $p = 0.006$). These preliminary relationships suggested that athletes with higher dispositional anxiety tended to experience stronger situational responses and exhibited lower performance consistency.

3.2 Confirmatory factor analysis

Confirmatory Factor Analysis (CFA) was conducted to validate the measurement structure of the latent variables included in the model. The measurement model demonstrated good overall fit to the data: $\chi^2 (48) = 63.21$, $p = 0.07$, CFI = 0.97, TLI = 0.96, RMSEA = 0.045 (90% CI [0.000, 0.072]), and SRMR = 0.041.

Factor loadings for the state anxiety indicators were strong and statistically significant. Cognitive anxiety loaded on the latent state anxiety factor at $\lambda = 0.83$ ($p < 0.001$), while somatic anxiety loaded at $\lambda = 0.79$ ($p < 0.001$).

The performance stability latent construct also demonstrated strong indicator loadings: inverse variability ($\lambda = 0.74$), inverse coefficient of variation ($\lambda = 0.81$), and aggregated shot-to-shot residuals ($\lambda = 0.77$), all significant at $p < 0.001$.

These results confirmed the adequacy of the measurement model for subsequent structural analyses.

3.3 Structural equation model

The SEM testing the hypothesized relationships among anxiety variables and shooting performance demonstrated good overall model fit: $\chi^2 (72) = 92.48$, $p = 0.053$, CFI = 0.96, TLI = 0.95, RMSEA = 0.049 (90% CI [0.000, 0.073]), and SRMR = 0.052. These indices meet commonly recommended criteria for acceptable model fit. As shown in Table 1, trait anxiety significantly predicted state anxiety ($\beta = 0.53$, SE = 0.08, $p < 0.001$), supporting Hypothesis 1. State anxiety negatively predicted shooting accuracy ($\beta = -0.31$, SE = 0.10, $p = 0.002$), supporting Hypothesis 2.

Table 1. Structural path coefficients

Path	β	SE	p
Trait Anxiety $\rightarrow$ State Anxiety	0.53	0.08	< 0.001
State Anxiety $\rightarrow$ Performance Stability	-0.42	0.1	< 0.001
State Anxiety $\rightarrow$ Shooting Accuracy	-0.31	0.10	0.002
Trait Anxiety $\rightarrow$ Performance Stability	-0.24	0.09	0.013
Performance Stability $\rightarrow$ Shooting Accuracy	0.56	0.09	< 0.001

In figure No. 3 State anxiety also negatively predicted performance stability ($\beta = -0.42$, SE = 0.10, $p < 0.001$), indicating that higher anxiety was associated with greater shot-to-shot variability. Performance stability significantly predicted shooting accuracy ($\beta = 0.56$, SE = 0.09, $p < 0.001$), demonstrating that athletes who maintained greater motor consistency achieved higher scores.

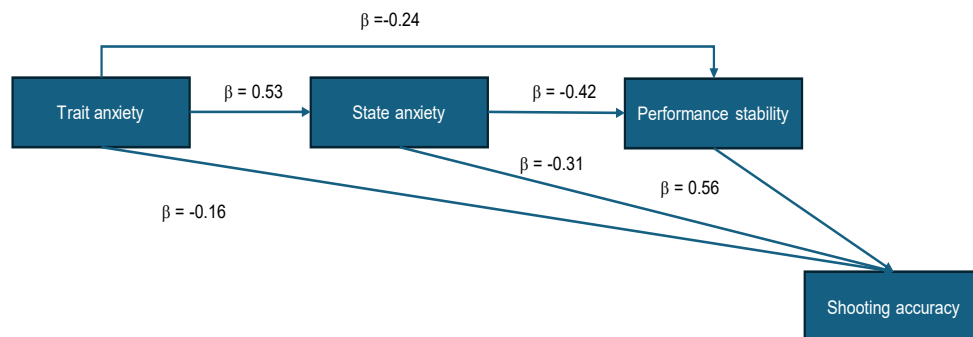


Figure 3. Structural Equation Model path diagram

Trait anxiety also demonstrated a direct negative effect on performance stability ($\beta = -0.24$, $SE = 0.09$, $p = 0.013$) and a smaller direct effect on shooting accuracy ($\beta = -0.16$, $SE = 0.07$, $p = 0.021$). Overall, the structural model explained 37% of the variance in shooting accuracy ($R^2 = 0.37$) and 31% of the variance in performance stability ($R^2 = 0.31$).

3.4 Mediation analysis

Bootstrapped mediation analysis (5,000 resamples) examined whether state anxiety mediated the relationship between trait anxiety and shooting accuracy. Trait anxiety significantly predicted state anxiety ($\beta = 0.51$, $SE = 0.09$, $p < 0.001$). State anxiety negatively predicted shooting accuracy ($\beta = -0.38$, $SE = 0.11$, $p = 0.002$).

The indirect effect was significant: Indirect effect = -0.19 95% CI $[-0.34, -0.07]$. Because the direct effect remained significant ($\beta = -0.17$, $p = 0.041$), the mediation was partial. These findings indicate that athletes with higher trait anxiety tend to experience higher state anxiety, which in turn reduces shooting performance.

3.5 Moderation Analysis

Moderation analysis examined whether self-confidence buffered the negative impact of state anxiety on performance. The interaction term State Anxiety $\times$ Self-Confidence was significant ($\beta = 0.29$, $SE = 0.10$, $p = 0.006$), indicating that the relationship between anxiety and performance varied as a function of athletes' confidence levels. Simple slope analyses (Table 2) were conducted to examine the conditional effects of state anxiety on shooting accuracy at different levels of self-confidence (-1 SD, mean, and $+1$ SD).

Table 2. Simple slopes for the interaction between state anxiety and self-confidence predicting shooting accuracy

Self-confidence level	b	p valor
Low (-1 SD)	-0.051	< 0.001
Mean	-0.34	0.0004
High ($+1$ SD)	-0.16	0.180

The results indicate that state anxiety strongly predicted performance decline at low levels of self-confidence, whereas this relationship became weaker and statistically non-significant at high levels of self-confidence. Thus, the negative effect of anxiety on performance decreased as self-confidence increased (Figure 4).

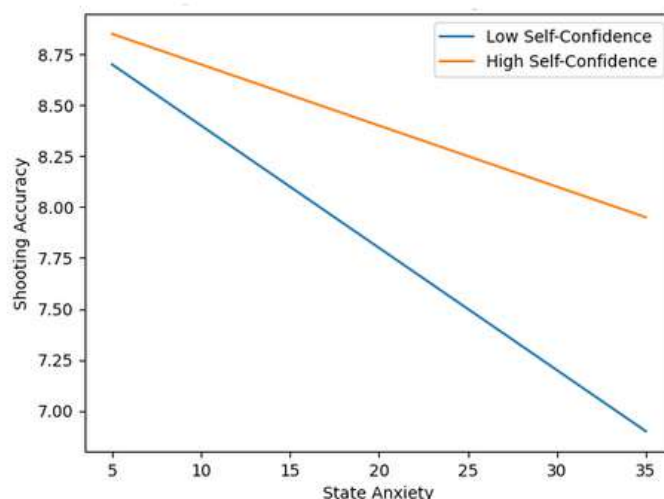


Figure 4. Moderation interaction plot of state anxiety and self-confidence predicting shooting accuracy.

3.6 Nonlinear anxiety-performance relationship

Hierarchical regression analyses were conducted to examine potential nonlinear effects. Step 1 included the linear anxiety predictor, while Step 2 introduced the quadratic term. Results indicated that state anxiety significantly predicted shooting accuracy ($\beta = -0.37$, $p = 0.003$). The addition of the quadratic term significantly improved model fit ($\Delta R^2 = 0.07$, $p = 0.018$), suggesting a curvilinear relationship (Figure 2). The quadratic coefficient was significant ($\beta = -0.26$, $p = 0.021$), indicating a performance decline at higher anxiety levels, consistent with inverted-U or catastrophe-type patterns (Figure 5).

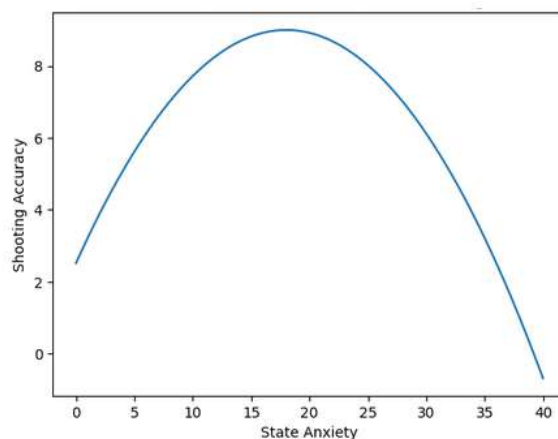


Figure 5. Quadratic relationship between state anxiety and shooting accuracy.

3.7 Multilevel modeling

Because shooting performance consisted of repeated shots nested within athletes, hierarchical linear modeling was used to partition variance across levels. The unconditional model revealed an intraclass correlation coefficient (ICC) of 0.42, indicating that 42% of the variance in shooting accuracy occurred between athletes, while 58% occurred within athletes across shots.

The Level 1 predictor (shot number) showed a small but significant effect on shot accuracy ($\beta = -0.012$, $SE = 0.004$, $p = 0.003$), suggesting a slight decline in performance across successive shots within a shooting series. At Level 2, state anxiety significantly predicted the intercept of shooting accuracy ($\gamma_{01} = -0.043$, $SE = 0.012$, $p = .001$), indicating that athletes with higher pre-performance anxiety tended to produce lower overall shot scores.

Trait anxiety also predicted the intercept ($\gamma_{02} = -0.027$, $SE = 0.011$, $p = 0.017$), although the magnitude of the effect was smaller. Together, Level 2 predictors explained approximately 24% of the between-athlete variance in shooting accuracy (pseudo- $R^2 = 0.24$).

3.8 Bayesian supplementary analysis

Bayesian regression analyses provided additional evidence supporting the observed relationships. The posterior distribution for the effect of state anxiety on shooting accuracy produced a mean estimate of $\beta = -0.31$ with a 95% credible interval $[-0.49, -0.12]$.

Bayes Factors indicated strong evidence for the effect of state anxiety on shooting accuracy ($BF_{10} = 18.6$) and moderate evidence for the effect on performance stability ($BF_{10} = 7.9$). Evidence for the direct effect of trait anxiety on shooting accuracy was weaker but still supported ($BF_{10} = 3.4$).

3.9 Effect sizes

Effect sizes were interpreted following conventional guidelines. The regression effect of state anxiety on shooting accuracy corresponded to a medium effect size ($f^2 = 0.18$), while the effect of performance stability on shooting accuracy approached a large effect ($f^2 = 0.26$). The multilevel ICC value of 0.42 indicated a substantial proportion of variance attributable to differences between athletes.

The findings of this study highlight several important implications for coaches, sport psychologists, and athletes involved in precision sports such as archery. Because shooting accuracy depends strongly on motor consistency, attentional control, and emotional regulation, training programs should incorporate structured psychological preparation alongside technical practice.

The results demonstrate that elevated state anxiety significantly reduces shooting accuracy and increases shot-to-shot variability, suggesting that athletes benefit from strategies aimed at regulating situational anxiety prior to and during competition. Psychological skills training programs that include breathing regulation, progressive muscle relaxation, attentional refocusing, and pre-shot routines may

help athletes stabilize physiological arousal and reduce intrusive cognitive interference that disrupts motor execution. In addition, the moderating role of self-confidence indicates that athletes with stronger confidence are less vulnerable to the negative effects of anxiety. Consequently, coaching programs should emphasize confidence-building strategies such as mastery-based training progression, goal setting, positive performance feedback, and mental imagery designed to reinforce successful performance expectations.

The identification of nonlinear anxiety-performance dynamics also suggests that moderate competitive arousal may support attentional readiness rather than impair performance. Coaches should therefore avoid attempting to eliminate anxiety completely and instead help athletes reinterpret physiological activation as facilitative energy that can enhance focus. Furthermore, the multilevel findings indicating substantial within-athlete performance variability highlight the importance of training athletes under simulated pressure conditions that mimic real competitions, including time constraints, scoring pressure, and audience presence. Such environments can help athletes develop resilience to moment-to-moment anxiety fluctuations and maintain stable motor patterns under stress.

Finally, because performance stability was shown to mediate the relationship between anxiety and shooting accuracy, integrating psychological regulation strategies with technical shooting drills may improve the consistency of motor execution during competition.

Several limitations should be considered when interpreting the results of the present study. First, cross-sectional design restricts the ability to establish definitive causal relationships among anxiety, confidence, and performance variables. Although the structural equation model provides theoretically grounded directional pathways, longitudinal or experimental research designs would be necessary to confirm causal dynamics over time.

Second, the study involved a relatively small sample of 65 university archers, which may limit the generalizability of the findings to other competitive levels such as elite, national, or recreational athletes. Differences in experience, training intensity, and psychological preparation may influence the strength of anxiety-performance relationships across populations.

Third, anxiety and confidence were assessed using self-report psychological scales, which may be influenced by subjective interpretation or response bias. While these instruments demonstrate acceptable reliability and validity, incorporating objective physiological indicators such as heart rate variability, electrodermal activity, or cortisol responses could provide a more comprehensive assessment of athletes' stress and arousal levels.

Fourth, shooting performance was evaluated in a simulated competitive environment. Although efforts were made to replicate realistic competition conditions, laboratory-based simulations may not fully reproduce the psychological pressure experienced during official tournaments.

Finally, the model focused primarily on trait anxiety, state anxiety, self-confidence, and performance stability; however, additional psychological constructs such as attentional focus, coping strategies, emotional regulation, and resilience may also influence performance in precision sports. Future research should continue

to expand the understanding of anxiety-performance relationships in precision sports by addressing the limitations identified in the present study. Longitudinal studies following athletes across training cycles or competitive seasons would allow researchers to examine how trait anxiety, state anxiety, and performance outcomes evolve over time and influence long-term skill development.

Experimental interventions evaluating psychological skills training programs could also provide causal evidence regarding the effectiveness of anxiety-regulation and confidence-enhancement strategies in improving motor performance.

In addition, future studies should aim to include larger and more diverse samples of athletes across different levels of expertise to determine whether the relationships observed in this study remain consistent in elite or international competitors. Integrating physiological monitoring technologies, such as heart rate variability sensors or wearable stress tracking devices, may help capture real-time emotional and physiological responses during competition.

Researchers may also benefit from applying dynamic analytical methods, including time-series modeling or continuous performance tracking, to better understand how moment-to-moment fluctuations in anxiety influence motor coordination during shooting sequences. Finally, expanding theoretical models to incorporate additional psychological variables such as attentional control, emotional regulation strategies, and resilience could provide a more comprehensive framework for explaining how psychological states influence performance in precision sports.

4. CONCLUSIONS

The present study investigated the relationship between competitive anxiety and shooting performance among university archers using a comprehensive analytical framework that combined correlational analysis, multilevel modeling, and structural equation modeling. The findings provide strong evidence that competitive anxiety is a multidimensional psychological construct that influences performance through both direct and indirect mechanisms affecting motor execution and performance stability.

The results demonstrated that trait anxiety significantly predicts state anxiety prior to competition, confirming that stable dispositional tendencies shape athletes' situational emotional responses in competitive contexts. Elevated state anxiety was associated with both reduced shooting accuracy and greater performance variability, indicating that situational anxiety interferes with the execution of precise motor actions required in archery. These findings support theoretical predictions from multidimensional anxiety frameworks and attentional control perspectives, which suggest that anxiety disrupts cognitive resources necessary for maintaining concentration and motor precision.

Performance stability emerged as a key mechanism linking psychological states to performance outcomes. Athletes who maintained more consistent shot patterns achieved higher overall scores, and performance stability partially mediated the negative effects of anxiety on shooting accuracy. This finding highlights the importance of motor consistency as a central determinant of success in precision

sports and demonstrates how psychological states translate into observable variations in motor execution.

The study also identified a significant moderating role of self-confidence. Athletes with higher levels of confidence were less negatively affected by anxiety, suggesting that confidence functions as a psychological resource that helps maintain attentional control and motor coordination under competitive pressure. This protective effect underscores the importance of psychological training strategies aimed at strengthening athletes' confidence and coping skills.

In addition, the identification of a nonlinear relationship between state anxiety and shooting performance provides support for theoretical models proposing that moderate levels of arousal may facilitate performance, whereas excessive anxiety can lead to rapid performance deterioration. This finding emphasizes the complex and dynamic nature of the anxiety-performance relationship and highlights the need for individualized psychological regulation strategies in precision sports.

Multilevel modeling further revealed that a substantial proportion of performance variability occurs within athletes across shots, indicating that moment-to-moment psychological fluctuations during competition play an important role in performance outcomes. This result suggests that successful athletes must develop the capacity to maintain motor consistency despite ongoing emotional and cognitive fluctuations during performance sequences.

Overall, the present study contributes to the sport psychology literature by integrating multiple analytical approaches to examine how dispositional anxiety, situational emotional states, and motor performance processes interact in archery. The findings demonstrate that competitive anxiety affects performance through complex pathways involving attentional control, motor stability, and psychological resilience. Understanding these relationships provides valuable insight for the development of psychological training programs designed to enhance performance consistency and emotional regulation in precision sports.

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ANALYSIS OF EEG ACTIVITY WITH BINAURAL BEATS DURING THE ASSEMBLY OF A PRODUCT USING LEGO BRICKS

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Resumen: Los pulsos binaurales constituyen una forma de estimulación auditiva capaz de modular la actividad cerebral y favorecer estados cognitivos como la atención, la concentración y la relajación. Este estudio evaluó el efecto de los pulsos binaurales sobre la actividad electroencefalográfica (EEG) y el desempeño en una tarea de ensamblaje de un producto utilizando bloques LEGO, considerando principios de **ergonomía cognitiva** para analizar la interacción entre el participante, la tarea y el entorno. Participaron 13 adultos jóvenes que realizaron la tarea en dos condiciones: control (sin pulsos binaurales) y experimental (con pulsos binaurales en el rango beta, 15 Hz). La actividad EEG se registró con un sistema de 16 canales siguiendo el sistema internacional 10–20, evaluando las ondas alfa (9–14 Hz) y beta (15–30 Hz) en las regiones prefrontal (AF3, AF4), temporal (F7, F8) y occipital (O1, O2). Se utilizó el índice beta/alfa para determinar posibles incrementos en fatiga cognitiva. Los resultados mostraron que, en la mayoría de los participantes, la exposición a pulsos binaurales aumentó la potencia de las ondas alfa y beta en varias regiones cerebrales sin inducir fatiga significativa, lo que sugiere que la estimulación auditiva favorece un estado de alerta consciente combinado con relajación. Estos hallazgos indican que los pulsos binaurales pueden mejorar la atención y el desempeño en tareas manuales complejas, con implicaciones potenciales en contextos educativos, cognitivos y de optimización ergonómica.

Palabras clave: pulsos binaurales, EEG, ondas alfa, ondas beta, ensamblaje manual, ergonomía cognitiva.

Relevancia para la ergonomía: Los hallazgos sugieren que la estimulación auditiva podría influir en procesos relacionados con la atención y la eficiencia en tareas manuales complejas. El estudio aporta evidencia preliminar sobre la interacción entre estimulación auditiva, actividad cerebral y desempeño en tareas de construcción, lo que podría tener implicaciones en contextos de diseño ergonómico, aprendizaje y optimización del rendimiento en entornos laborales y educativos.

Abstract: Binaural beats are a form of auditory stimulation capable of modulating brain activity and promoting cognitive states such as attention, concentration, and

relaxation. This study evaluated the effects of binaural beats on electroencephalographic (EEG) activity and performance in a product assembly task using LEGO blocks, incorporating principles of **cognitive ergonomics** to assess the interaction between participants, task, and environment. Thirteen young adults (6 men and 7 women) completed the task under two conditions: control (without binaural beats) and experimental (with binaural beats in the beta range, 15 Hz). EEG activity was recorded using a 16-channel system following the international 10–20 system, focusing on alpha (9–14 Hz) and beta (15–30 Hz) waves in prefrontal (AF3, AF4), temporal (F7, F8), and occipital (O1, O2) regions. The beta/alpha ratio was used to assess potential increases in cognitive fatigue. Results showed that, in most participants, exposure to binaural beats increased alpha and beta wave power across several brain regions without inducing significant fatigue, suggesting that auditory stimulation supports a state of conscious alertness combined with relaxation. These findings indicate that binaural beats may enhance attention and performance in complex manual tasks, with potential applications in educational, cognitive, and ergonomic optimization contexts.

Keywords. binaural beats, EEG, alpha waves, beta waves, manual assembly, cognitive ergonomics.

Relevance to Ergonomics: These findings suggest that auditory stimulation could influence processes related to attention and efficiency in complex manual tasks. The study provides preliminary evidence on the interaction between auditory stimulation, brain activity, and performance in construction tasks, which may have implications for ergonomic design, learning, and performance optimization in workplace and educational settings.

1. INTRODUCTION

The study of brain activity during the performance of cognitive tasks is a central area within cognitive neuroscience. Among the most widely used techniques for recording neural activity in humans is the electroencephalogram (EEG), a non-invasive method that measures cortical electrical activity using electrodes placed on the scalp. This technique offers extremely high temporal resolution, making it a suitable tool for analyzing the neural processes that occur during the performance of cognitive tasks in real time (Niedermeyer & Lopes da Silva, 2005).

The EEG signal reflects the synchronous activity of cortical neural populations and can be analyzed in terms of different frequency bands. These bands have been associated with different functional states of the brain, including sleep, relaxation, attention, and active cognitive processing (Başar et al., 2001). In particular, the beta band (13–30 Hz) has been linked to states of alertness, active information processing, motor control, and sustained attention.

In recent years, there has been growing interest in the study of sensory stimulation techniques capable of modulating brain activity. One such technique is stimulation using binaural pulses, also known as binaural beats. This phenomenon

occurs when two pure tones of slightly different frequencies are presented simultaneously.

For example, if a 240 Hz tone is presented to the left ear and a 255 Hz tone to the right ear, the brain perceives a beat of approximately 15 Hz. Several researchers have suggested that this perceived frequency can induce neural synchronization or entrainment, i.e., a tendency for brain activity to oscillate at the same frequency as the auditory stimulus (Wahbeh et al., 2007).

Because of this phenomenon, binaural beats have been investigated as a possible tool for inducing specific mental states. Different frequency ranges have been associated with different potential effects: Theta (4–8 Hz): deep relaxation and meditative states; Alpha (8–12 Hz): relaxation and relaxed attention; Beta (13–30 Hz): concentration and alertness; Gamma (>30 Hz): cognitive integration (Gao et al., 2014).

However, despite growing interest in this phenomenon, empirical results have been inconsistent. Some studies have found positive effects on cognitive performance, while others have not observed significant changes (Beauchene et al., 2017).

In turn, cognitive neuroscience research has used various experimental tasks to study processes such as planning, problem solving, and visuospatial coordination (Lane, 1998). Among these tasks, object construction and assembly activities have proven particularly useful because they require the integration of multiple cognitive functions.

Building with LEGO blocks is an important and justifiable form of experimentation because it involves interpreting visual instructions, fine motor skills, sequential planning, working memory, and spatial reasoning. These characteristics make assembly tasks a suitable model for studying the interaction between cognitive processes and brain activity.

The objective of this study is to analyze electroencephalographic activity during an assembly task using LEGO blocks under the influence of binaural pulses in the beta range, in order to explore possible changes in brain activity associated with attention and cognitive performance.

1.1 Electroencephalogram and cognitive processes

The electroencephalogram is based on recording the differences in electrical potential generated by the synchronous activity of cortical neuronal populations. These signals are captured by electrodes placed on the scalp following standardized location systems, the most widely used being the international 10–20 system.

EEG signal analysis can be performed using different techniques, including spectral analysis, coherence analysis, and event-related potentials (ERPs) (Gao et al. 2014).

Spectral analysis allows the EEG signal to be broken down into different frequency components, which facilitates the identification of patterns associated with different functional states of the brain (Başar et al., 2001).

1.2 Binaural beats and neural synchronization

The phenomenon of binaural beats was first described by Heinrich Wilhelm Dove in 1839, although systematic study of it began later with research on auditory perception.

The processing of binaural beats occurs in the superior olivary complex, a structure in the brainstem involved in sound localization. The signal is then transmitted to auditory cortical regions where the perception of the rhythmic beat is generated.

Some researchers have proposed that this stimulation may induce changes in brain activity through neural synchronization mechanisms. This phenomenon, known as entrainment, implies that neural oscillations can adjust to the frequency of an external stimulus (Colzato et al., 2012).

1.3 Visuospatial cognition and construction tasks

Construction tasks involve distributed neural networks that include: dorsolateral prefrontal cortex, posterior parietal cortex, premotor cortex, supplementary motor areas

These regions are involved in processes such as: planning, spatial organization, object manipulation, motor control

Previous studies have shown that during visuospatial problem-solving tasks, there is an increase in beta and gamma band activity in frontoparietal regions. (Colzato et al 2012).

2. OBJECTIVES

The research aimed to evaluate brainwave behavior when using binaural beats while performing a task involving assembling a product with LEGO blocks. The study focused on analyzing the effects of binaural beats on mood and cognitive performance, observing how specific frequencies can modulate emotions and concentration during the execution of complex manual tasks.

Cognitive ergonomics, understood as the interaction between the person, the task, and the environment, was considered to evaluate how auditory stimulation could optimize efficiency and comfort in manipulation and assembly tasks.

3. METHODOLOGY

3.1 Participants

Thirteen young adults (7 men, 6 women) aged between 20 and 28 participated. All had normal hearing and no history of neurological or psychiatric disorders. The procedure was explained to them and they signed informed consent forms.

3.2 Experimental procedure

The purpose of this study is to observe the behavior of brain waves when using binaural beats while performing a task involving assembling a product with Legos. The focus is on observing the effect of binaural beats on people's positive mood while performing a task. etc.

Alpha and beta rhythms were used to stimulate people's behavior and emotions while assembling the product. Each frequency range promotes a different behavior and emotion. (Pawar et al. 2017).

Each participant completed a product assembly task using LEGO blocks under two conditions: a control condition without auditory stimulation and an experimental condition with binaural beats in the alpha (9–14 Hz) and beta (15–30 Hz) ranges. Alpha rhythms were used to induce relaxation and creativity, and beta rhythms to promote alertness and mindful attention (Pawar et al., 2017).

3.3 EEG recording

A 16-channel EEG system was used following the 10–20 system. The regions of interest were: Prefrontal: AF3, AF4; Temporal: F7, F8; Occipital: O1, O2. The power of the alpha and beta bands was analyzed, and the beta/alpha index proposed by Freeman et al., 2000, was calculated to assess cognitive fatigue.

Table 1. Alpha and Beta Brain Waves (Pawar et al. 2017)

Brain Waves	Condition
Alpha (9 Hz-14 Hz)	Relaxed, Calm, meditation, creative, visualization
Beta (15 Hz-30 Hz)	Awake, normal alert consciousness

3.4 Data analysis

EEG activity was compared with and without binaural beats. The results were visualized per person and brain region, evaluating increases, decreases, or absence of changes in alpha and beta waves.

4. RESULTS

The behavior of alpha and beta brain waves in the prefrontal, temporal, and occipital regions was analyzed. In the prefrontal area, only channels AF3 and AF4 were used; in the temporal area, channels F7 and F8 were used; and in the occipital area, channels O1 and O2 were used. Finally, the Beta/Alpha algorithm proposed by Freeman et al. 2000, was used to determine whether there was an increase in fatigue with the use of binaural beats. A significant decrease in beta/alpha is associated with increases in fatigue levels.

4.1 Beta Wave Behavior with and without Binaural Beats

Figure 1, shows the beta wave behavior with and without binaural beats for subjects 1 through 5. The graphs were separated by subject range for better data visualization.

Where CPB (with binaural beats) and SPB (without binaural beats) in all graphics.

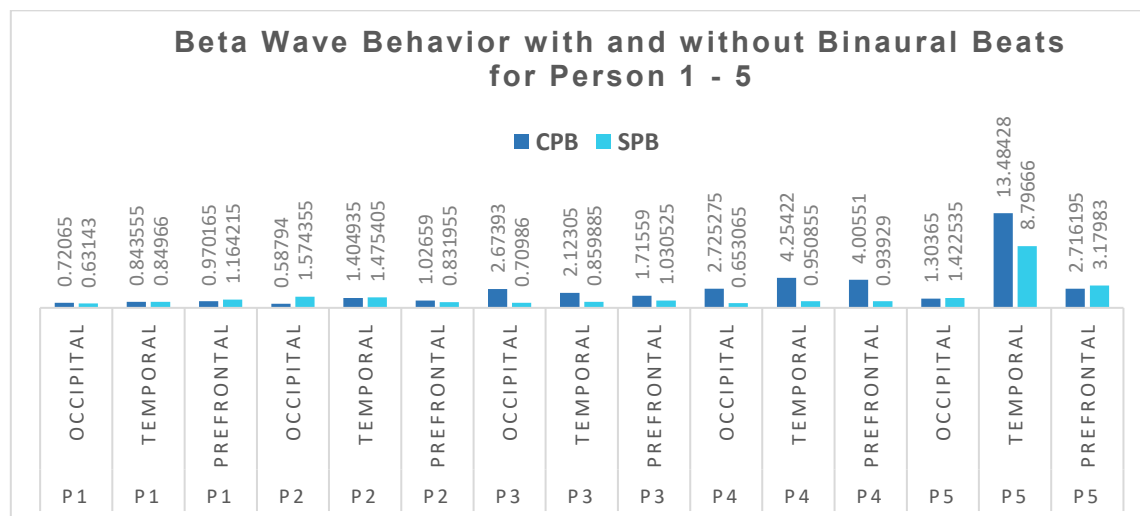


Figure 1. Beta Wave Behavior with and without Binaural Beats for Person 1 - 5.

In person 1, no changes were observed in the different brain regions; in person 2, beta CPB decreased in the occipital region; in persons 3 and 4, beta CPB increased in all three regions; and in person 5, beta increased in the temporal region and decreased slightly in the prefrontal area. In summary, two persons showed an increase in beta CPB in all three regions, and one person showed an increase in the temporal area.

Figure 2 shows the behavior of the beta wave with and without binaural beats in subjects 6 to 10.

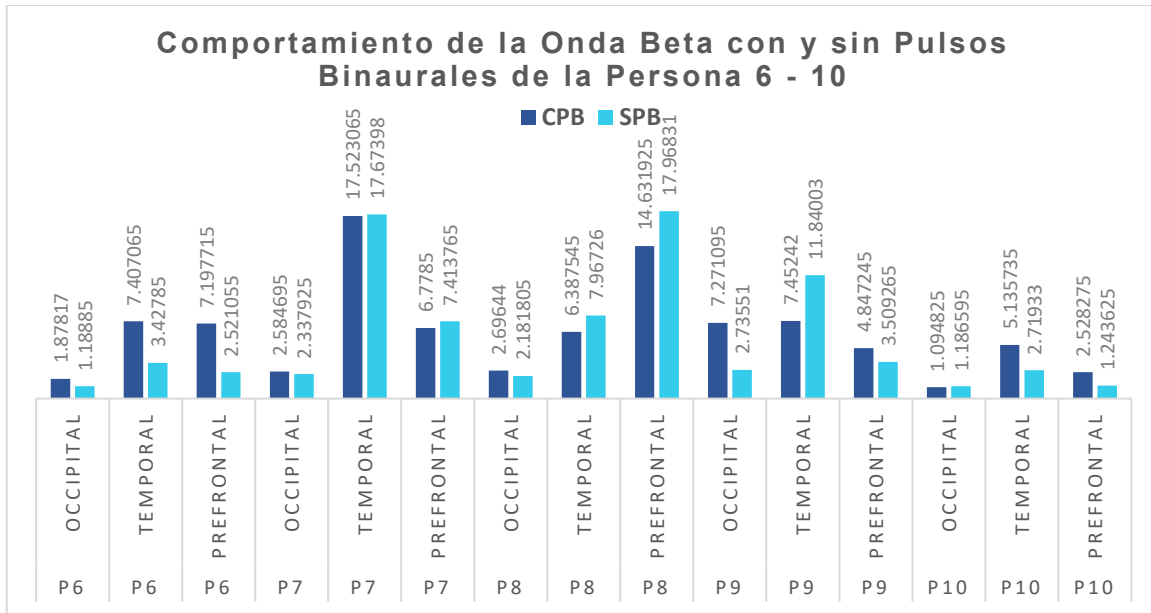


Figure 2. Beta wave with and without binaural beats from person 6–10.

In person 6, beta CPB increased in all three brain regions; in person 7, it remained unchanged; in persons 8 and 9, it increased in the occipital area and decreased in the temporal and prefrontal regions; and in person 10, it increased in the temporal and prefrontal areas. In summary, in two persons, beta CPB increased in the temporal and prefrontal areas, and in two others, it decreased in the same regions. There was not much variation in the occipital area.

Figure 3 shows the beta wave behavior with and without binaural beats in subjects 11 to 13.

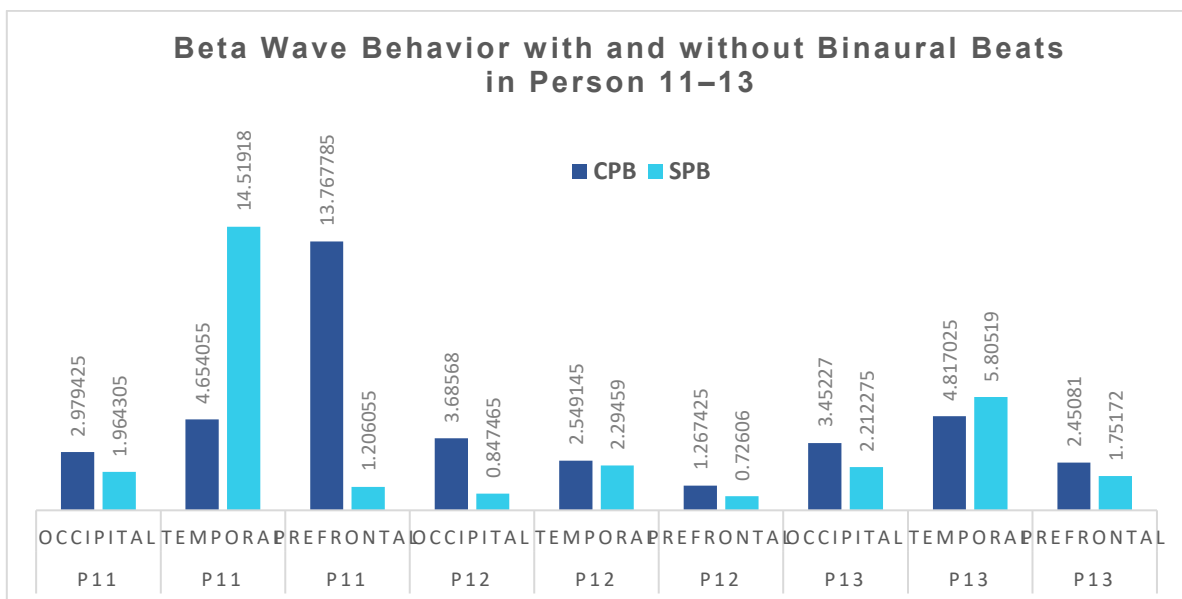


Figure 3. Beta waves with and without binaural beats in subjects 11–13.

In person 11, there was a decrease of beta CPB in the temporal area and an increase in the prefrontal and occipital areas, and a decrease in the temporal area; in person 12, there was an increase in all three regions; and in person 13, there was an increase in the occipital and prefrontal areas. In summary, there was an increase of beta CPB in the prefrontal and occipital areas in all three persons.

4.2 Alpha Wave Behavior with and without Binaural Beats

Figure 4 shows the behavior of the alpha wave with and without binaural beats for subjects 1 through 5.

In figure 4, person 1 there were no significant changes; in persons 2 and 5, there was an increase of alpha CPB in the temporal and prefrontal regions; in persons 3 and 4, there was an increase in all three regions.

In figure 5, subjects 6 and 7, there was an increase in alpha CPB in all three regions; in subject 8, there was a decrease in the prefrontal region; in subject 9, there was an increase in the occipital and prefrontal regions; and in subject 10, there was an increase in the temporal region and a decrease in the occipital and prefrontal regions. In summary, in three subjects there was an increase in the prefrontal region, and in four subjects there was an increase in the temporal and occipital regions.

Figure 6 shows the behavior of the alpha wave with and without binaural pulses in subjects 11 to 13.

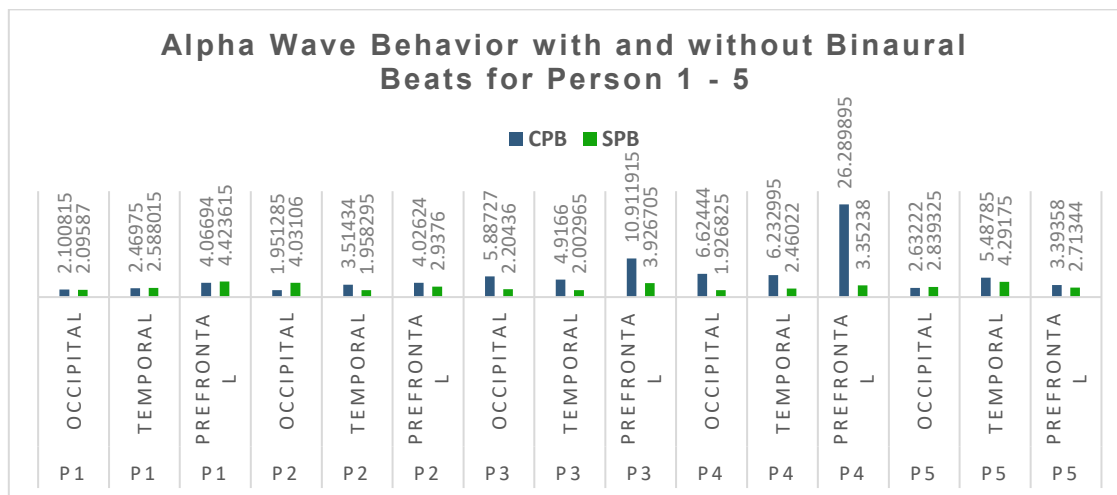


Figure 4. Alpha wave with and without binaural beats in person 1–5.

Figure 5 shows the behavior of the alpha wave with and without binaural beats in persons 6 to 10.

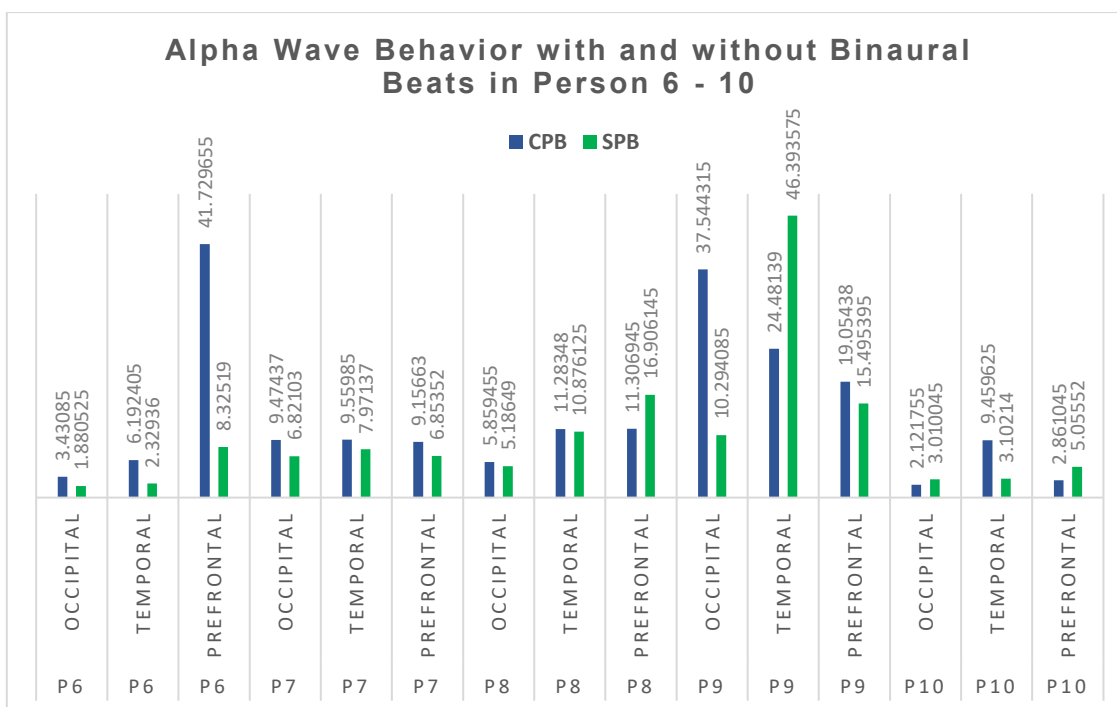


Figura 5. Alpha wave with and without binaural beats in person 6 – 10.

In figure 6, There was an increase of alpha CPB in the occipital region in subjects 11, 12, and 13. In the prefrontal region, there was an increase in subjects 11 and 12.

When evaluating the behavior of alpha and beta brain waves using binaural rhythms in the assembly of a Lego product, there was an increase in the three brain regions in most people. Sometimes it also decreased or remained unchanged. This is because each person reacts differently to any operation performed or stimulus from the environment.

In order to interpret the changes in alpha and beta brain waves in this study, the following graphs show the behavior of alpha, beta, and the beta/alpha index, which was used to evaluate whether fatigue occurred in people when using binaural pulses.

4.3 Behavior of Beta, Alpha, and Beta/Alpha Waves with and without Binaural Beats.

Figure 7 shows the behavior of the beta wave, alpha wave, and beta/alpha fatigue index with and without binaural beats.

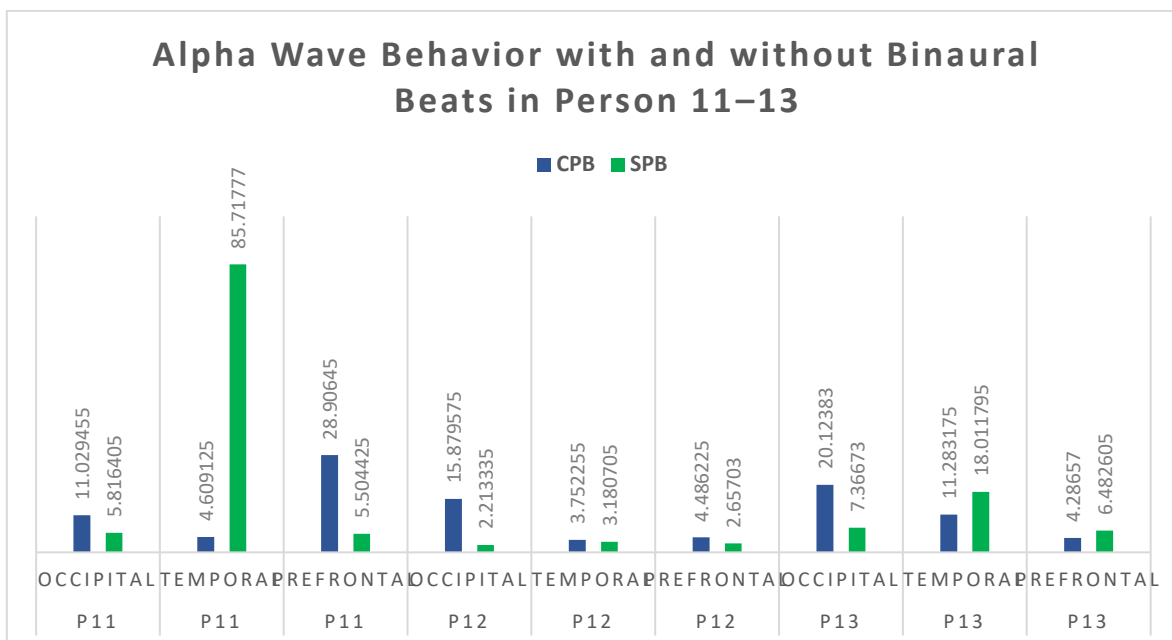


Figure 6. Alpha waves with and without binaural beats in subjects 11-13.

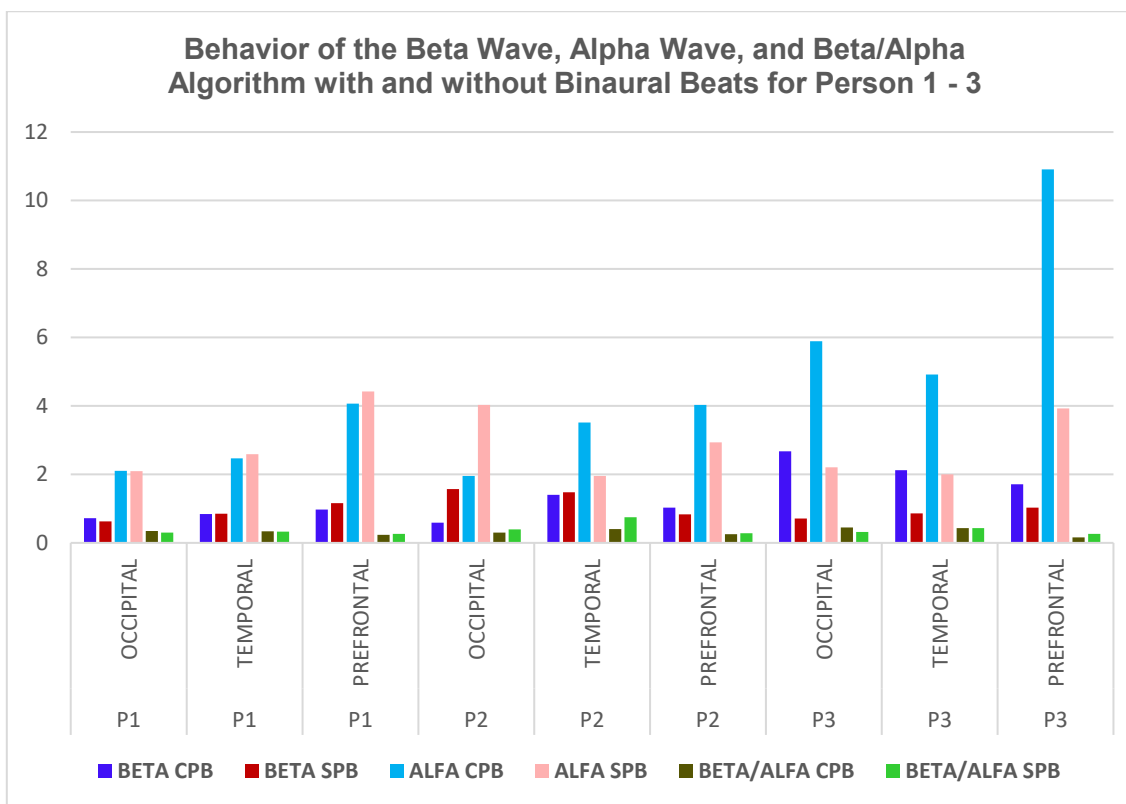


Figure 7. Beta, Alpha, Beta/Alpha waves with and without binaural beats in person 1-3.

In figure 7; In person 1, the CPB alpha and beta waves remain unchanged. In person 2, CPB alpha and beta decreased in the occipital region, increased in the prefrontal region, alpha increased in the temporal region, but beta remained unchanged in the temporal region. In person 3, CPB alpha and beta increased in all three regions. There were no changes in the beta/alpha fatigue index.

Figure 8 shows the behavior of the beta and alpha waves and the beta/alpha fatigue index with and without binaural beats.

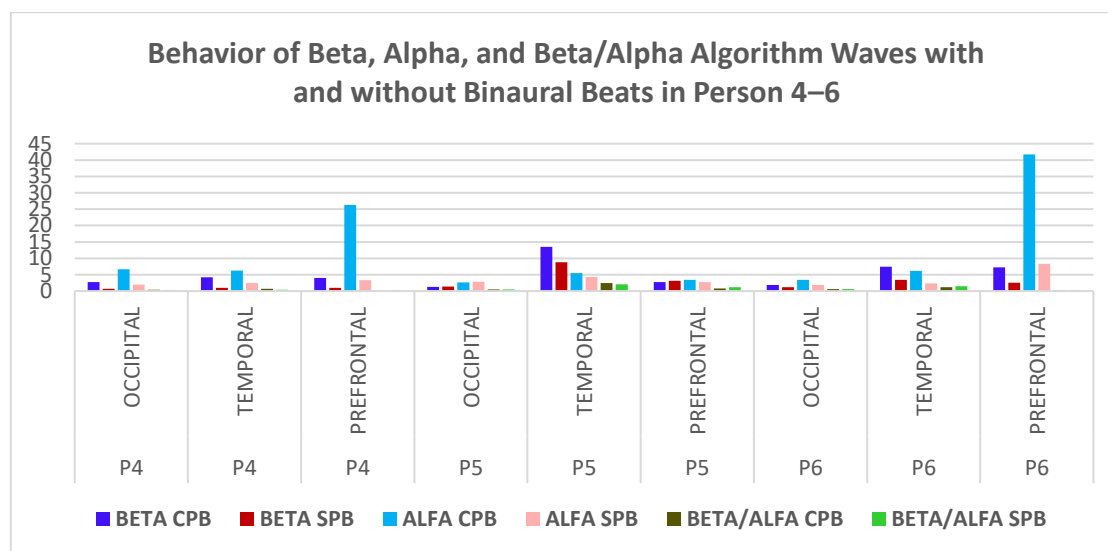


Figure 8. Beta, Alpha, Beta/Alpha waves with and without binaural beats in subjects 4-6.

In figure 8, In subjects 4, 5, and 6, alpha and beta CPB increased in the occipital, temporal, and prefrontal regions. There were no changes in the beta/alpha fatigue index.

Figure 9 shows the behavior of the beta wave, alpha wave, and beta/alpha fatigue index with and without binaural beats.

In figure 9, person 7, CPB beta in the occipital, temporal, and prefrontal areas remains unchanged, and CPB alpha shows a slight increase. In person 8, CPB beta and alpha increase in the occipital and temporal areas but decrease in the prefrontal area. In contrast, in person 9, CPB beta and alpha increase in the prefrontal and occipital areas and decrease in the temporal area. In summary, alpha and beta CPB increased in the occipital region in all three subjects, and in the prefrontal region in two subjects. There are no changes in the beta/alpha fatigue index.

Figure 10 shows the behavior of the beta wave, alpha wave, and beta/alpha fatigue index with and without binaural pulses.

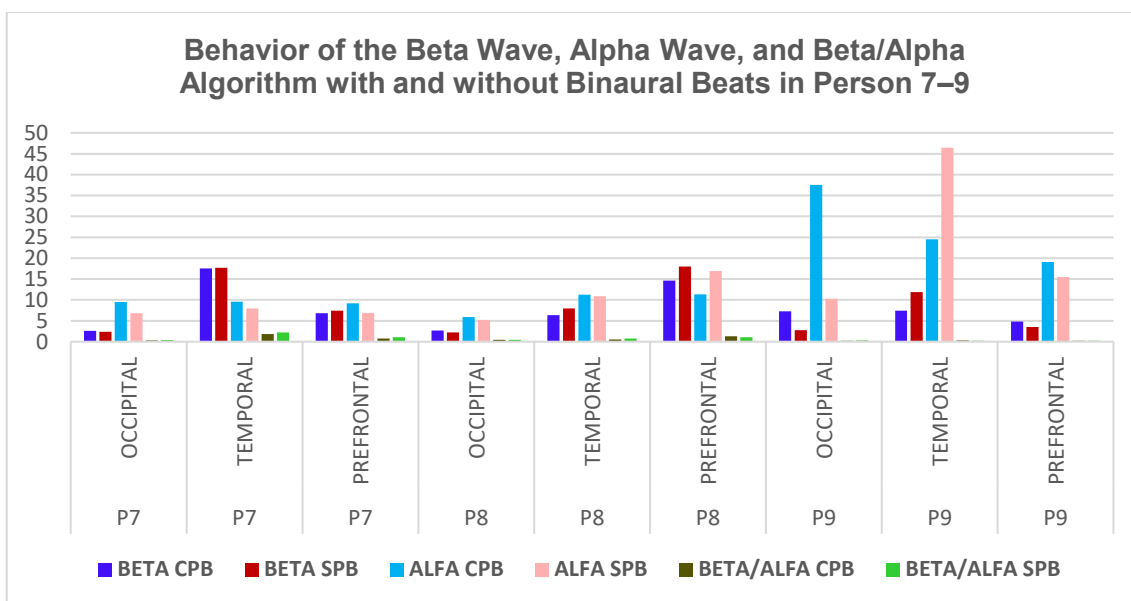


Figure 9. Beta, Alpha, Beta/Alpha waves with and without binaural beats in subjects 7-9.

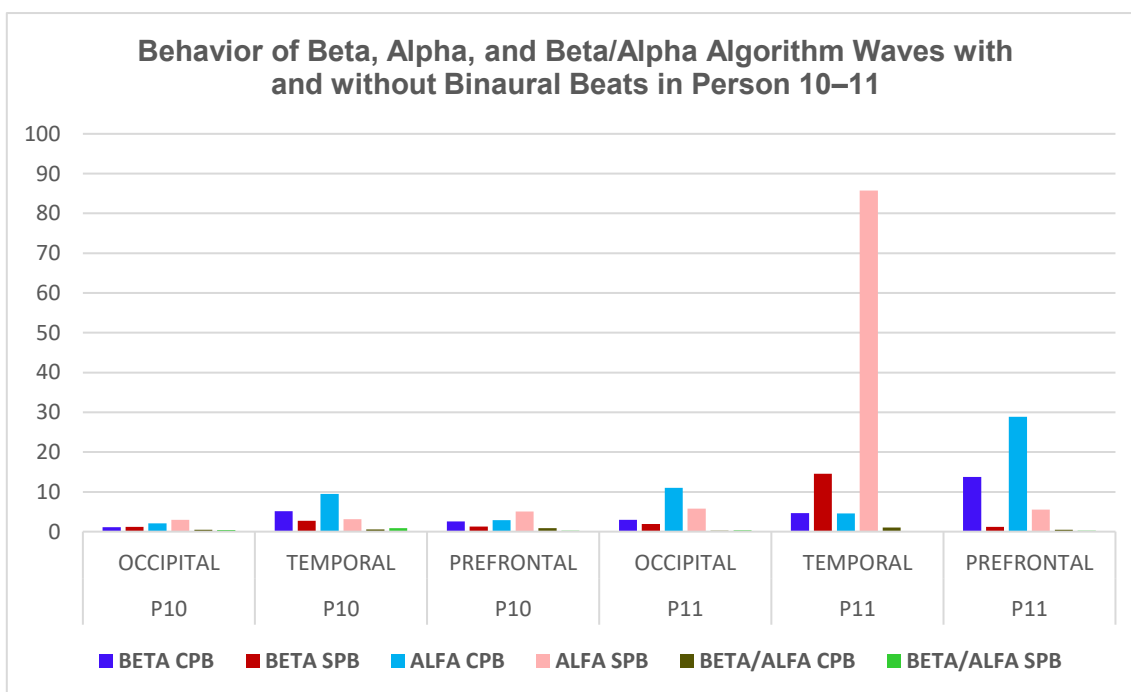


Figure 10. Beta, Alpha, Beta/Alpha waves with and without binaural beats in subjects 10-11.

In subject 10, alpha and beta CPB increased in the temporal region, and only beta CPB increased in the prefrontal region. In person 11, alpha and beta CPB

increased in the occipital and prefrontal regions and decreased in the temporal region. There are no changes in the beta/alpha fatigue index.

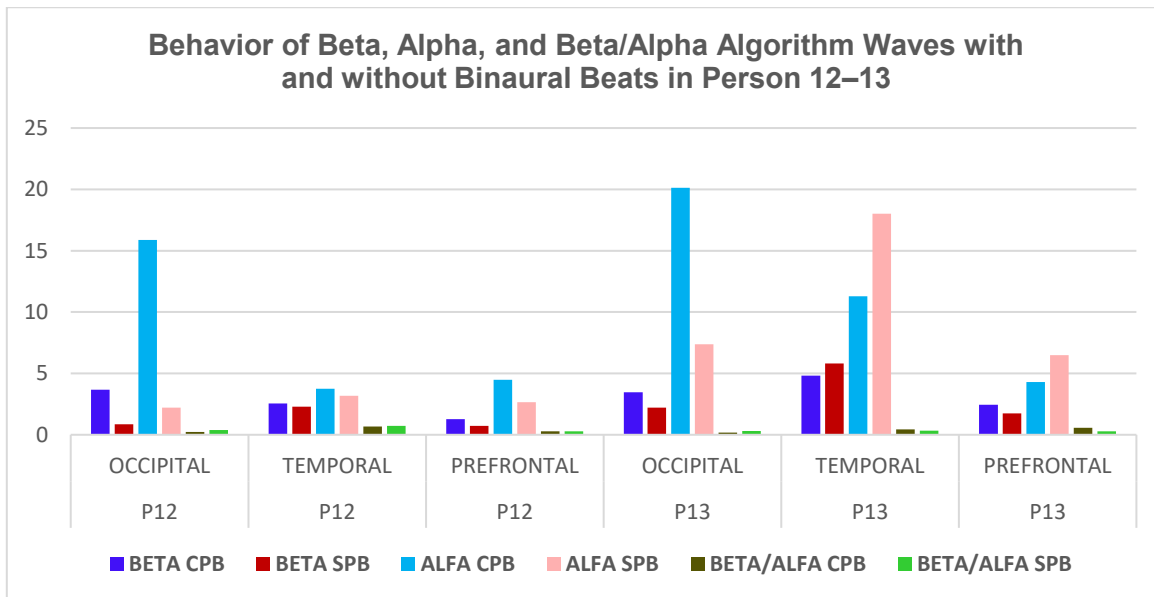


Figure 11. Beta, Alpha, Beta/Alpha waves with and without binaural beats in person 12-13.

Figure 11 shows that the CPB alpha and beta waves in person 12 increased in all three brain regions and in person 13 increased in the occipital and prefrontal regions. There were no changes in the beta/alpha fatigue index.

In summary, the analysis of alpha and beta brain wave behavior in 13 people in the three regions of the brain: prefrontal, temporal, and occipital. Alpha and beta CPB in 9 out of 13 people increase in the prefrontal area, and in 8 out of 13 people increase in the temporal and occipital areas. These results show that there are changes in brain waves when using binaural beats for assembling a product with Legos. The relative increase in alpha and beta waves causes the person to work in a relaxed cognitive state while allowing the person to be in a state of conscious alertness. As there was an increase in alpha waves in some regions, which is a sign of increased fatigue, the beta/alpha fatigue index was used to assess whether there was an increase in fatigue in the different regions.

Next, a paired t-test was performed to see if there was a difference in the fatigue index when assembling a product with and without binaural beats. The average power of the 13 people in each region was used. Figures 12, 13, and 14 show the paired t-test.

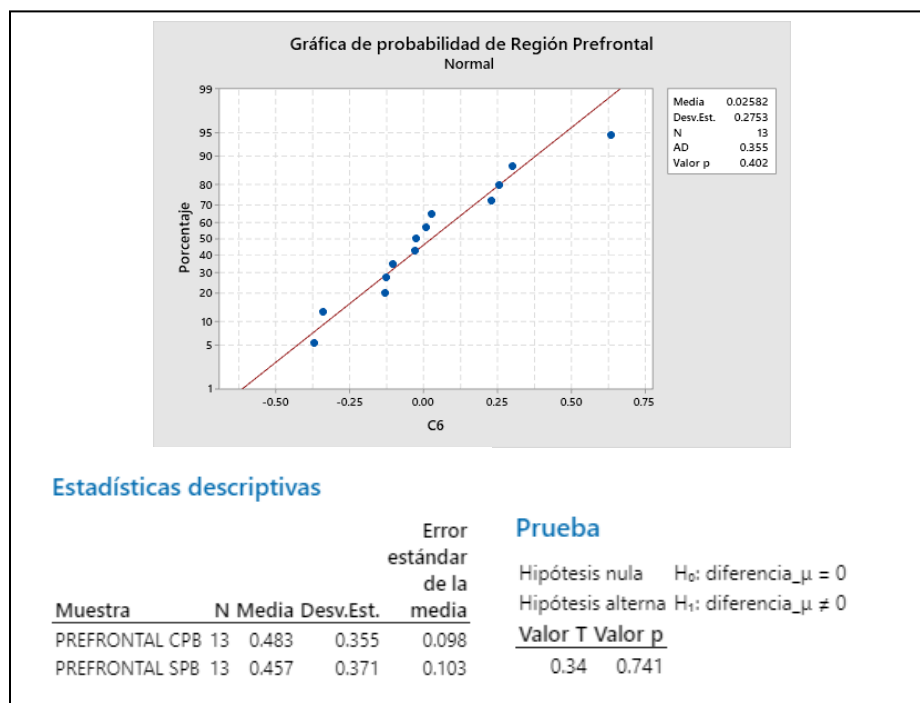


Figure 12. Paired t-test Prefrontal Region Fatigue Index Beta/Alpha

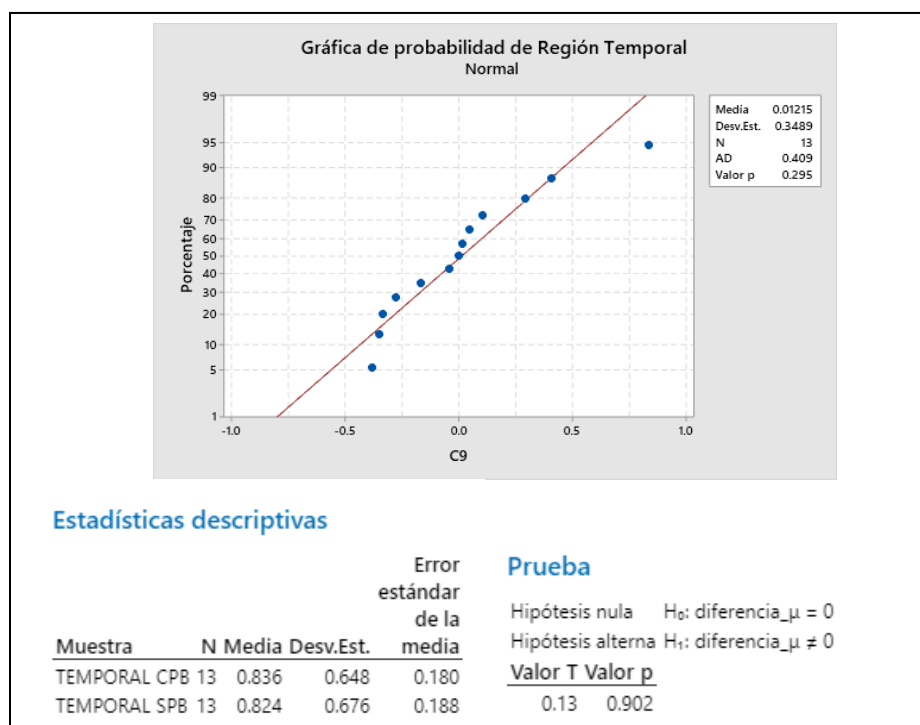


Figure 13. Paired t-test Temporal Region Fatigue Index Beta/Alpha

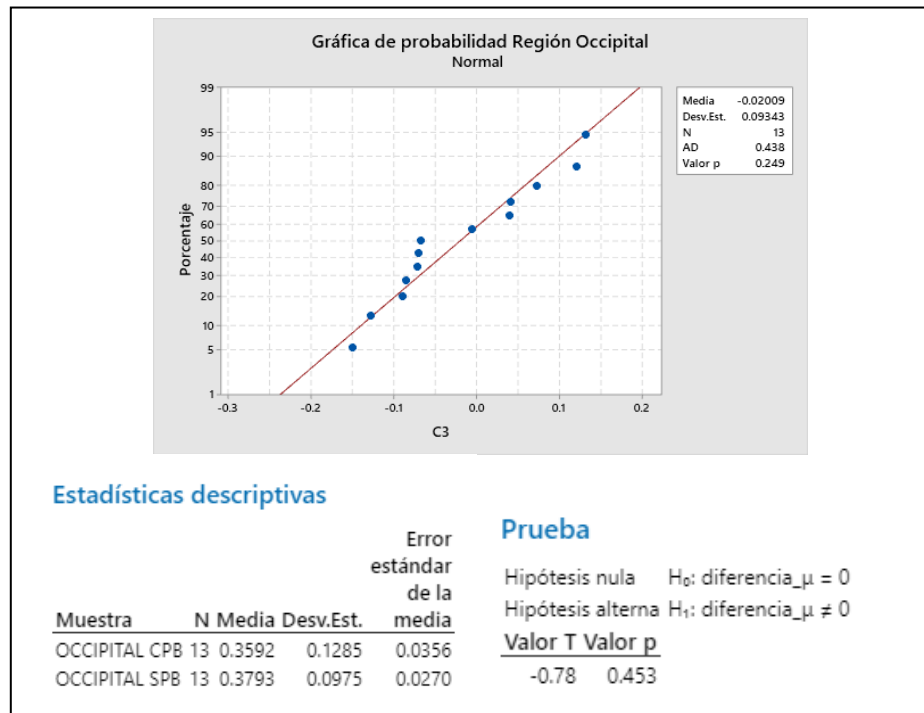


Figure 14. Paired t-test Temporal Region Fatigue Index Beta/Alpha

Table 2 below summarizes the data from Figures 12, 13, and 14 and concludes that there are no differences in the beta/alpha fatigue index in the prefrontal, temporal, and occipital regions when using binaural rhythms.

Table 2. Paired T-test Prefrontal, Temporal, Occipital Region

Paired t-test				
REGION	CPB(with BB)	SPB (without BB)	p_value	DIFFERENCES
PREFRONTAL	0.483	0.457	0.741	No differences
TEMPORAL	0.836	0.824	0.902	No differences
OCCIPITAL	0.3592	0.3793	0.453	No differences

5. CONCLUSIÓN

Binaural pulses modulate EEG activity during assembly tasks, increasing alpha and beta waves in the prefrontal, temporal, and occipital regions without increasing cognitive fatigue. This suggests a state of conscious alertness combined with relaxation, which is useful for improving attention and performance in complex manual tasks. The findings emphasize the importance of combining auditory stimulation and ergonomics in educational and work environments to optimize user efficiency and well-being. Further studies with more participants and different

binaural pulse frequencies are recommended to confirm and generalize these results.

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ERGONOMIC ANALYSIS AND PROPOSAL FOR A BAKERY IN CIUDAD JUAREZ

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Resumen: El siguiente estudio fue elaborado con la intención de hacer análisis en una estación de trabajo de una panadería con un enfoque en la ergonomía. Con la implementación del método de estudio de Marley y Kumar, donde se identificaron molestias musculoesqueléticas que los trabajadores presentan, y puede haber daños irreparables en la salud, donde no solo es expuesta la comodidad del trabajador si no también afecta en su salud. Con ayuda de distintos métodos de estudio de la ergonomía como REBA para analizar posturas mal adoptadas y NIOSH que analiza el peso máximo que se considera seguro levantar en condiciones específicas de tarea, se realizó un diseño de estación ergonómico, donde se implementaron los principios antropométricos de la ergonomía para disminuir todas aquellas molestias musculoesqueléticas y desordenes de traumas acumulativos. En los resultados se detectaron diversas situaciones y posiciones de riesgo donde es necesario la intervención de la ergonomía para así reducir los accidentes en el área de trabajo.

Palabras clave: Ergonomía, panadería, salud, REBA, NIOSH, posturas, rediseño.

Relevancia para la ergonomía: El análisis ergonómico en una panadería es relevante porque permite identificar tareas repetitivas, posturas forzadas, manejo de cargas y movimientos que pueden generar molestias musculoesqueléticas en los trabajadores. Estos factores, al estar presentes de manera constante durante la jornada laboral, incrementan el riesgo de desarrollar trastornos por trauma acumulativo y otros problemas de salud.

La publicación de este artículo es importante porque ofrece información específica sobre los riesgos ergonómicos que se presentan en pequeñas empresas de sector alimentario, en esta ocasión una panadería. Esto contribuye a fomentar la importancia de incorporar principios ergonómicos en cualquier entorno de trabajo, promoviendo la seguridad, el bienestar y la productividad del personal.

Abstract: The following study was carried out with the intention of analyzing a workstation in a bakery with an ergonomic focus. By applying the Marley and

Kumar assessment method, musculoskeletal discomforts experienced by the workers were identified, revealing the potential for irreversible health damage, as not only worker comfort is compromised, but their overall health as well. With the support of various ergonomic evaluation methods such as REBA, used to analyze poorly adopted postures, and NIOSH, which assesses the maximum weight considered safe to lift under specific task conditions an ergonomic workstation design was developed. In this design, anthropometric principles of ergonomics were implemented to reduce musculoskeletal discomfort and cumulative trauma disorders. The results revealed various risk situations and postures where ergonomic intervention is necessary in order to reduce accidents in the workplace.

Keywords: Ergonomics, bakery, health, REBA, NIOSH, postures, redesign.

Relevance to ergonomics: The ergonomic analysis in a bakery is relevant because it allows the identification of repetitive tasks, forced postures, load handling, and movements that can generate musculoskeletal discomfort in workers. These factors, when present constantly throughout the workday, increase the risk of developing cumulative trauma disorders and other health problems. The publication of this article is important because it provides specific information about the ergonomic risks present in small businesses within the food sector, in this case, a bakery. This contributes to promoting the importance of incorporating ergonomic principles in any work environment, enhancing worker safety, well-being, and productivity.

1. INTRODUCTION

The ergonomic design of workstations in food production environments, such as bread-making, plays a fundamental role in protecting employee health and optimizing productivity. This study focuses on the production area of a local bakery in Ciudad Juárez, where work activities are carried out entirely by hand or with simple machinery that assists in preparing the dough mixture, including tasks such as kneading heavy masses, baking at high temperatures, handling utensils, and performing repetitive molding operations.

During the observations and software-assisted analysis, various deficiencies were identified in the layout of the workspace and the production tools used. These included inadequate worktable heights, frequent handling of loads exceeding safe lifting capacity, exposure to heat sources, and the recurrent adoption of awkward postures and repetitive movements. Such conditions can lead to health problems such as musculoskeletal disorders, overexertion injuries, carpal tunnel syndrome, and lower back pain, all of which negatively affect workers' health, efficiency, and long-term well-being. Therefore, this study seeks to evaluate the current state of the work environment and identify existing ergonomic risk factors. The results will serve as the basis for proposing specific improvements grounded in ergonomic and anthropometric principles, thus contributing to a safer and more efficient workplace.

In recent years, numerous cases of health problems related to bakery work have been documented, not only those traditionally considered occupational diseases but also issues associated with manual material handling and the constant repetition of work cycles, which can lead to systemic and chronic conditions. Additionally, there are other problems directly linked to poorly designed workstations, which cause pain or injuries in different parts of the body. Among the most common disorders found in bakeries are lower back pain often caused by lifting sacks and maintaining poor kneading postures and shoulder or elbow tendinitis, associated with repetitive movements and excessive force. These problems are related to non-modifiable factors such as genetics, age, or gender-specific issues, as well as modifiable factors, which constitute the main focus of our study, through the proposal of an ergonomic redesign of the workstation and production methods.

1.1 Ergonomics in the food sector

Ergonomics applied to the food sector focuses on adapting processes, tools, and working conditions to the capacities and limitations of the worker, with the aim of preventing injuries and improving productive efficiency. In bakeries, this approach becomes especially important because activities are carried out predominantly by hand and under demanding conditions, such as repetitive cycles, handling of heavy loads, continuous exposure to heat sources, and prolonged work shifts that significantly increase physical fatigue and musculoskeletal risks. The application of ergonomics makes it possible to design safer workstations, reduce unnecessary effort, and optimize productivity, ensuring a healthy and sustainable work environment. (Fazi et al., 2020)

1.2 Ergonomic conditions specific to the bakery process

The work carried out in bakeries presents a series of characteristics that differentiate it from other environments in the food sector. The combination of intensive manual tasks and constant exposure to various environmental conditions generates specific ergonomic risks:

Dough kneading and preparation: Activities that require significant strength, repetitive movements of the arms and torso, and leaning postures that increase the biomechanical load on the lower back and upper limbs.

Baking and thermal handling: Continuous exposure to heat sources, opening heavy ovens, removing hot trays, and prolonged work near high temperatures, which increases physical fatigue and thermal stress.

Shaping and forming pieces: Repetitive movements, manual precision, and moderate force within short periods of time, which can lead to tendinitis, carpal tunnel syndrome, and muscular fatigue.

Internal transport of supplies: Handling bags of flour, trays, baking sheets, and finished products, which often exceed the recommended limits established by ergonomic standards when no auxiliary tools are available.

Physical work environment: Slippery floors, limited space, lack of adequate ventilation, insufficient lighting, or poor workspace layout, all of which increase the likelihood of forced postures and compensatory movements.

During this evaluation, the conditions of dough kneading, dough preparation, molding, and piece forming were analyzed and understood through ergonomic techniques and methods, identifying the main risk factors present in each stage of the production process. The levels of physical effort, movement repetitiveness, worker postures, and characteristics of the physical environment were observed in order to determine how these elements directly influence biomechanical load and the development of potential musculoskeletal injuries. (Chyuan, 1999)

1.3 Occupational biomechanics in kneading and dough-handling activities

The activities of kneading and handling dough involve a combination of demanding biomechanical movements, such as pushing, pulling, twisting, and compressing, which require intense involvement of the trunk, shoulders, and upper limbs. Manual kneading demands repetitive force, successive trunk bending, and wide arm movements that place high loads on the lower back and joints. When tools or partial machinery are used, the risks do not completely disappear, as the user's posture, grip, working height, and equipment design may introduce new biomechanical factors that increase muscle strain and physical wear. Understanding these elements is essential for designing interventions that reduce mechanical load and prevent overexertion-related injuries. (Chen, 2020)

1.4 Importance of ergonomic analysis in micro and small enterprises

In micro and small bakeries, where most processes are carried out manually and resources for automation are limited, ergonomic analysis is crucial to ensure both worker health and the operational viability of the business. Ergonomics not only reduces the incidence of musculoskeletal injuries but also improves productivity, decreases operation times, prevents absenteeism, and reduces costs associated with workplace accidents. Studies conducted in Mexican bakeries show a high frequency of ergonomic problems, such as lower back pain, tendinitis, and repetitive strain injuries, attributable to poorly designed workstations and lack of training. Therefore, implementing ergonomic policies becomes a strategic necessity that contributes both to worker well-being and to the competitiveness of the business within the food sector. (Ahasan, 2002)

1.5 Modifiable and non-modifiable factors in the worker's physical performance

The physical performance of a worker in a bakery is influenced by a combination of modifiable and non-modifiable factors that determine their ability to carry out tasks safely, efficiently, and without risk of injury. Understanding this distinction is essential for designing effective ergonomic interventions that address the real needs of the staff.

Table 1. Modifiable and non-modifiable factors

Modifiable Factors	Non-Modifiable Factors
Physical conditioning and strength	Age
Posture and body mechanics	Sex
Workstation design	Genetic predispositions
Workload distribution	Anthropometric characteristics
Work pace and rest breaks	Previous injuries (permanent limitations)
Tool and equipment usage	Bone structure and natural joint mobility
Training and ergonomic awareness	

Intervening in modifiable factors makes it possible to significantly reduce the risk of injury, improve worker comfort, and increase operational efficiency. Together, both modifiable and non-modifiable factors provide a comprehensive view of the worker's physical condition, allowing the design of ergonomic strategies that promote a safe, healthy, and productive work environment. (Sharma et al., 2014)

1.6 Problem statement

Work in traditional bakeries in Mexico is characterized by continuous manual activities that require significant physical exertion, inclined postures and repetitive movements. In the specific case of the bakery evaluated in Ciudad Juárez, these tasks are performed without a defined ergonomic structure, using tools and furniture that do not meet adequate anthropometric criteria for workers. This combination results in a significant increase in musculoskeletal risks, especially affecting the upper extremities, lower back, and joints exposed to repetitive motion.

They are exposed to discomfort in shoulders, wrists, forearms, back, and neck, as well as unnecessary exertion during kneading, lifting flour sacks, shaping pieces, or handling hot trays. Additionally, it was identified that the design of the workstation and the distribution of the work area do not allow for efficient or safe workflow, causing bakers to adopt forced postures and compensatory movements that, if left unaddressed, may lead to chronic injuries such as tendinitis, carpal tunnel syndrome, lower back pain, and Cumulative Traumatic Disorders (CTDs).

Therefore, the central problem addressed in this study is the identification, analysis, and quantification of ergonomic risks present in bakery activities, as well as the determination of modifiable factors that allow for viable, low-cost solutions that can be applied within the real context of the business, ensuring a safer, healthier, and more efficient work environment.

2. OBJECTIVES

2.1 General objective

Apply various ergonomic and anthropometric principles to assess the risks of the artisanal bread-making workstation in a local bakery. All data will be analyzed using the REBA method and frame by frame analysis software. Additionally, the NIOSH method will be implemented to develop recommendations and proposals for improving the workstation.

2.1 Specific objectives

1. Identify the worker's musculoskeletal problems
2. Analyze the workstation
3. Evaluate ergonomic risk factors
4. Assess the maximum load weight the worker should lift
5. Design a new workstation with appropriate distribution and dimensions

3. METHODOLOGY

This study consisted of six phases, in which different ergonomic approaches were integrated, including methods to analyze the workplace, modify the work area, readapt it, and provide the worker with a safe and unobstructed space when performing their tasks.

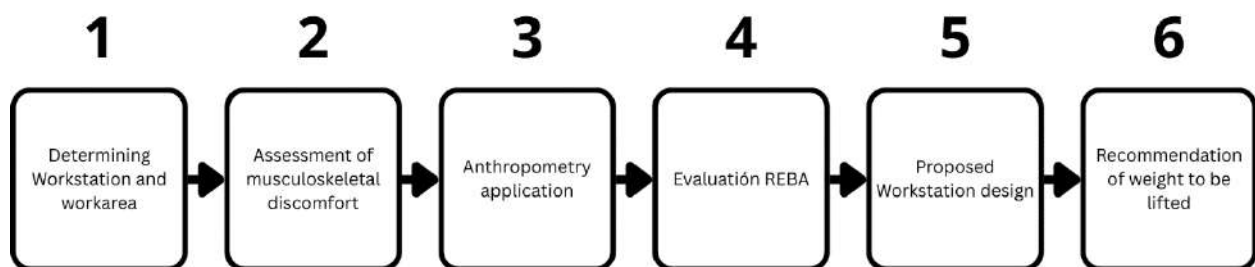


Figure 1. Phases of methodology

3.1 Phase 1: Determining the workstation and work area

First, we conducted a personal review of the equipment and work environment of the employees in a local bakery in Ciudad Juarez, where the various operations performed by the workers who prepare and bake the bread were observed. During this investigation, the kneading department was specifically analyzed, which consists of two workstations: the “kneading table” and the “mixing machines”.



Figure 2. Kneading table



Figure 3. Mixing machines

In this area, three male workers were analyzed. Their anthropometric data such as weight, height, and body measurements could not be obtained due to their refusal to provide personal information. However, it was possible to obtain their ages, which allowed the investigation to continue. Below, the ages of the subjects will be presented, along with the process they follow to knead the well-known “white breads” that are later sent to the baking area.

Table 2. Ages of the workers analyzed

	Age
Worker 1	31 years
Worker 2	35 years
Worker 3	59 years

During our inspection, several operations harmful to the operators were identified. In addition to safety and health risks, we observed worker fatigue, poor workstation design, and a non-ergonomic distribution of materials. These are the operations carried out in the kneading area.

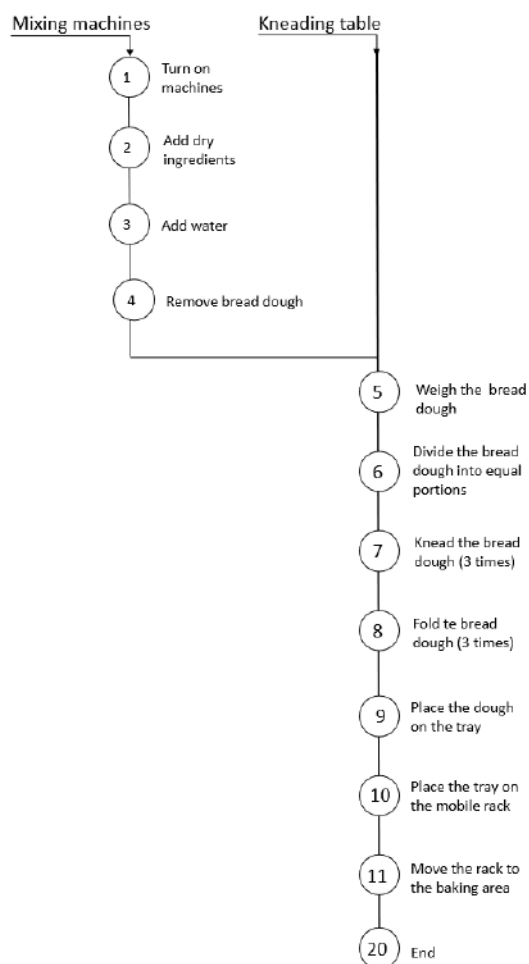
Operations diagram of the kneading area

Figure 4. Operations diagram of the kneading area

3.2 Phase 2: Assessment of musculoskeletal discomfort

To complement the ergonomic analysis carried out in the kneading area of the bakery, the Marley and Kumar (1996) instrument was applied, which allows identifying the frequency and level of discomfort experienced by the workers in different regions of the body during the last 30 days.

This assessment was administered to the three workers who directly participate in kneading and dough-preparation activities, with the purpose of obtaining an accurate overview of the musculoskeletal discomfort associated with their daily tasks.

The main objective of this application was to detect the body areas with the greatest presence of pain or discomfort, essential information for understanding the biomechanical effects of the operations and guiding the development of ergonomic interventions.

The data collected allowed, in later stages of the study, the proposal of adjustments to workstations and preventive strategies that contribute to significantly reducing the accumulation of fatigue, the risk of injuries, and the discomfort reported by the workers.

MUSCULOSKELETAL DISCOMFORT ASSESSMENT

Instructions: Please consider your perception of the frequency and level of discomfort experienced during the last 30 days and write the number corresponding to the phrase that indicates the frequency and discomfort in the indicated body parts. Follow the example for completing this section. Remember that your answers are confidential.
PLEASE DO NOT LEAVE ANY BOXES UNANSWERED

Frequency

0 - Never

1 - Rarely
(A few times a month)

2 - Frequently
(A few times a week)

3 - Constantly (Almost every day)

Example of survey completion:

2	5

Level of discomfort

0 - No discomfort

1

2 - Somewhat comfortable

3

4

5 - Moderate discomfort

6

7

8 - Very uncomfortable

9

10 - Extremely uncomfortable

Example

(Source: Marley and Kumar, 1996)

I, _____ (First and last name) consent to the use of the data collected by this instrument for academic and research purposes.

Position: _____ Institution: _____

Seniority: 1-5 years 6-10 years 11-20 years 21-25 years But 25

Sex: MH

Figure 5. Assessment of musculoskeletal discomfort presence applied

3.3 Phase 3: Analysis of operations

After the site visit and the initial visual observation, we proceeded to record a 15-minute video inside the bakery, where the operators' daily activities and the natural way they perform their tasks could be carefully examined. To accomplish this, we used the GOMPLAYER software, where the recorded video was uploaded. Following the project's practical guidelines, we requested the analysis of 200 frames. Each frame was extracted every 2 seconds, and the software registered them accordingly. Each frame was then saved and numbered from one to two hundred.

Next, the frames were classified into folders according to the type of activity captured in each image. The selection of frames was performed randomly using Excel randomization functions, and activity categories were established. The 100 selected frames represented a sample of the operator's total activities and responsibilities. After classifying them into their respective categories, we obtained a specific number of frames in each group, and with this information we calculated the frequency of each task to facilitate the distribution of activities per frame. It was established that all activities with a frequency greater than 10% required an individual task analysis. Additionally, one activity with a frequency of 9% was also analyzed due to its involvement in load lifting and the use of improper postures.

This analysis, carried out through the software, helps reveal safety factors and performance conditions in the work area, evaluate different tasks, and identify relevant positions and body parts so that we could propose improvements in the workspace, machinery layout, worktables, and distance distribution. This contributes to improving productivity as well as promoting the operator's health and well-being.

3.4 Phase 4: REBA evaluation method in the bakery

To evaluate the working conditions, present in the study, the REBA method was used an assessment tool developed by Hignett and McAtamney to analyze posture and determine the level of risk associated with work-related musculoskeletal disorders. This method makes it possible to systematically evaluate the critical tasks performed by the operator by assigning scores to the different body regions involved during the execution of each activity.

First, multiple frames were selected from the video analysis conducted in Phase 3, choosing those that most accurately represented the postures adopted during the various operations. In parallel, the dimensions and heights of the workstation components were recorded, along with the weights and forces handled by the workers, in order to properly classify the observations within the method's scoring scales.

REBA divides the analysis into two main groups: Group A, which includes the trunk, neck, and legs, and Group B, which includes the upper arms, lower arms, and wrists. Each body region is evaluated through a posture scoring scale that may be adjusted based on specific positional characteristics. Additional factors such as load or force, coupling quality, and activity level are then incorporated. Using the corresponding tables, a final score is obtained, indicating the degree of risk and the urgency of intervention.

Based on the results obtained in this phase, the main forced postures associated with musculoskeletal risk during the kneading process were identified. This information serves as a key foundation for the proposed modifications to the workstation, as well as for redesigning the area layout, reach distances, and equipment configuration, with the objective of reducing physical strain, improving safety, and promoting a more ergonomic and efficient working environment.

Table 3. Rapid Entire Body Assessment (REBA) format

Rapid Entire Body Assessment (REBA)				Date: / /	
Task:			Analyst:		
Group A		Group B			
Feature/Range	Score	Total	Feature/Range	Score	Total: Left and Right
Trunk			Upper Arms (Shoulders)		
Upright	1		Flexion: 0-20°	1	L R
Flexion: 0-30°	2	If back is twisted or tilted to side: +1	Extension: 0-30°	1	Arm Abducted / Extended: +1
Flexion: 30-60°	3		Flexion: 20-45°	2	
Flexion: 60-90°	4		Extension: >20°	3	
			Flexion: 45-60°	3	Shoulder Raised: +1
			Flexion: >60°	4	Arm Supported: +1
Neck			Lower Arms (Elbows)		
Flexion: 0-30°	1	If neck is twisted or tilted to side: +1	Flexion: 90-100°	1	L R
Flexion: >30°	2		Flexion: <90°	2	No Adjustments
			Flexion: >100°	2	
Legs			Wrists		
Bilateral (W) Bearing: Wk, Bk	1	Knee(s) Flexion: 90-60°: +1	Flexion: 0-15°	1	L R
Unilateral (W) Bearing: Unstable	2		Extension: 0-15°	1	Wrist Deviated / Twisted: +1
		Knee(s) Flexion: >60°: +2	Flexion: >15°	2	
			Extension: >15°	2	
Score from Table A			Score from Table B		
Load / Force			Coupling		
< 5 kg	0	Shock or Rapid Building: +1	Good	0	L R
< 11 kg	1		Fair	1	No Adjustments
5 - 10 kg	1		Poor	2	
11 - 22 kg	2				
> 10 kg	2		Unacceptable	3	Left Right
> 22 kg	2				
Score A (Table A + Load/Force Score)			Score B (Table B + Coupling Score)		
Activity			Activity Score		
One or more body parts are static for longer than 1 minute			+1		
Repetitive small range motions, more than 4 per minute			+1		
Rapid large changes in posture or unstable base			+1		
REBA Score (Score C = Activity Score)			REBA Score (Score C = Activity Score)		

3.5 Phase 5: Proposed Workstation design

Based on all the previous phases of the ergonomic analysis, we confirm that ergonomics will have an essential role in the new restructuring proposals. Not only will the tools and ingredients be redistributed, but the distances were also adapted according to levels of reach precision, normal, and maximum as well as the heights of the machines involved in tasks that include load handling. In these adjustments, the use of 95th and 5th percentiles will be crucial for the corresponding modifications, ensuring that the workstation fits the optimal operator for each activity.

The objective is to propose a new workstation in which ergonomic principles guarantee practical and sustainable solutions within the bakery, ultimately improving workers' well-being throughout their workdays.

3.6 Phase 6: Recommendation of weight to be lifted (NIOSH)

To evaluate the risk associated with manual load lifting in the kneading area and during dough handling in the bakery, the NIOSH method was applied using

specialized software responsible for calculating the Recommended Weight Limit (RWL) and the Lifting Index (LI).

This method is widely used in occupational ergonomics to determine whether a lifting task falls within safe parameters. Its equation considers multiple factors that directly influence the physical demands placed on the worker, including the horizontal distance of the object from the body, the initial and final lifting heights, the vertical displacement, task frequency, movement asymmetry, and the quality of the grip. Based on these parameters, the software identified lifting tasks that exceeded the RWL, indicating a high risk of musculoskeletal injuries, particularly in the lumbar region. These results highlight the need to redesign the workstation and optimize dough handling from its origin (mixing machines) to its destination (kneading table), ensuring that the loads handled remain within ergonomically acceptable limits.

“The attached program is based upon the standards recommended in Applications Manual for the Revised NIOSH Lifting Equation, DHHS (NIOSH) Publication No. PB94-176930, 1994. Every effort has been made to ensure the accuracy of the calculations, however, no warranty, either expressed or implied has been offered with this program. Copyright 2000, Neese Consulting, Inc.”

4. RESULTS

4.1 Results of assessment of musculoskeletal discomfort

After applying the Marley and Kumar assessment, various musculoskeletal discomforts were identified among the three evaluated workers. The affected body regions are presented below, along with the percentage proportion of the discomfort reported. In the visual representation, green indicates a low level of discomfort, yellow corresponds to a moderate level, and red reflects a high level of discomfort.

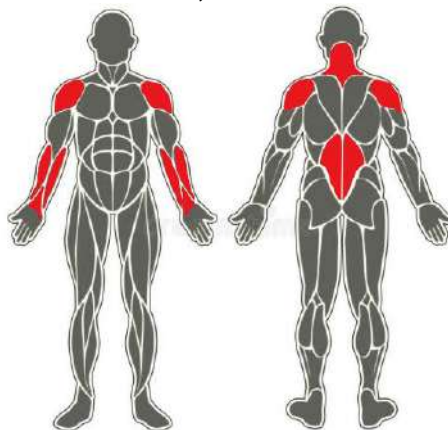


Figure 6. Musculoskeletal discomfort areas present



Figure 7. Histogram of the most affected areas

Table 4. Complete assessment of musculoskeletal discomforts

Area	Worker 1	Worker 2	Worker 3
Right shoulder	Red	Yellow	Green
Left shoulder	Red	Yellow	Green
Right wrist	Red	Red	Red
Left wrist	Red	Red	Red
Right forearm	Green	Yellow	Yellow
Left forearm	Yellow	Yellow	Red
Right arm	Red	Red	Red
Left arm	Yellow	Red	Red
Neck	Red	Yellow	Yellow
Back	Red	Red	Red
Right hip	Green	Green	Green
Left hip	Green	Green	Green
Right leg	Green	Green	Green
Left leg	Green	Green	Green
Right knee	Green	Green	Green
Left knee	Green	Green	Green
Right ankle	Green	Green	Green
Left ankle	Green	Green	Green

In this evaluation, it was observed that several body areas show discomfort levels classified in yellow and red, mainly in the arms, forearms, wrists, shoulders, and lower back, which is consistent with the repetitive and physically demanding nature of activities such as kneading, folding, reaching, and handling dough.

Although some body segments appear in green, indicating no or low discomfort, this pattern is found only in areas with lower physical demand, such as the legs, which is understandable since most of the effort in bakery work is placed on the upper limbs and trunk flexion.

The wrists and lower back were the most affected regions, as shown by the intense colors that represent frequent pain or constant discomfort. Wrist discomfort is mainly associated with repetitive movements and continuous impacts resulting from the traditional technique of kneading and folding the dough, which is performed almost entirely using manual force. Meanwhile, the lumbar area shows high levels of discomfort due to physical overload, awkward postures, and especially the need to bend over low worktables or handle heavy containers coming from the mixer. Although some body areas appear in green, indicating no or low discomfort, this pattern is observed only in segments with lower physical demand, such as the legs, which is understandable since most of the physical effort in a bakery relies on the upper limbs and trunk flexion. Overall, this histogram confirms the presence of muscular overload in the areas most involved in the bread production process and

highlights the need for ergonomic interventions to reduce the identified discomfort before it progresses to chronic injuries or cumulative trauma disorders (CTDs).

4.2 Analysis of operations

After capturing the frames with GOMPLAYER, we classified them into the following elements:

1.- Stooping

This includes all actions in which the worker flexes the trunk and, in many cases, the knees as well, to reach objects located at a low height, such as trays or when removing dough from the mixing machines. This activity involves repetitive lumbar flexion and, when not performed with proper technique, increases the load on the lower back and knees, which explains the presence of discomfort in the lumbar region and lower limbs in some of the frames analyzed.



Figure 9. Stooping element

2.- Reaching

This includes actions in which the worker extends the arm forward or to the sides to grab trays, dough, ingredients, or tools located outside the immediate comfort zone. This activity involves frequent shoulder elevation and slight trunk twisting, and is therefore mainly associated with discomfort in the shoulders, neck, and upper back, especially when objects are far away or above the recommended working height.



Figure 10. Reaching element

3.- Kneading

This represents the most physically demanding activity. It involves applying repetitive force to the dough, combining wrist flexion and extension, radial and ulnar deviations, along with a bent trunk posture. The continuous repetition of these movements' places significant load on the forearms, wrists, shoulders, and lower back, which aligns with the discomfort reported using the Marley and Kumar and REBA methods.



Figure 11. Kneading element

4.- Folding

This involves the movements used to give the final shape to the bread pieces, generally through a series of quick folds that involve wrist strikes and precise dough handling. This activity concentrates much of the fine repetitive work, with short but frequent movements, increasing strain on the wrists, hands, and forearm muscles, and promoting the development of disorders such as tendinitis and epicondylitis. It is important to note that during bread production, 16 loaves per minute are made (bimanual work), with 3 folds (wrist strikes) per loaf. Considering that 516 loaves are produced per workday, this results in 3,096 wrist strikes per day, making it the most critical risk factor identified in this study.



Figure 12. Folding element

5.- Lifting

This category includes actions in which the worker lifts, holds, or transports containers of dough, sacks of flour, trays, or heavy utensils. Due to the weights involved, such as 13.2 kg of dough per batch, this category is one of the most critical from an ergonomic standpoint, as it requires the simultaneous involvement of the lower back, shoulders, and upper limbs, increasing the risk of lumbar injuries and general muscular fatigue.



Figure 13. Lifting element

6.- Releasing

This includes the moments when the worker places the dough or already shaped pieces onto trays, tables, or equipment, thereby releasing the load held in their hands, as well as pouring dry ingredients into the mixing machines. Although it may appear to be a less demanding activity, it involves repetitive wrist extensions, grip changes, and rapid postural adjustments, which contribute to accumulated fatigue in the hands and forearms, especially when performed continuously throughout the workday.



Figure 14. Releasing element

7.- Idle time

This refers to intervals in which the worker is not performing any of the main productive activities and is in a more relaxed position, either standing without a load, walking slowly, or making minor adjustments in the work area. Although these periods are relatively short, they are ergonomically important because they allow for slight muscle recovery and a temporary reduction of physical load, helping to partially alleviate fatigue generated by more demanding tasks.



Figure 15. Idle time element

After explaining each of the seven activities, we proceeded to identify and understand the **most frequent tasks** within the process.

Table 5. Elements frequency

FRAME	PICTURE	NUMBER OF FRAMES	FREQUENCY	FREQUENCY PERCENTAGE	CUMULATIVE FREQUENCY
Steeping		28, 82, 162, 180, 183, 194, 196	7	7%	7%
Reaching		44, 48, 70, 72, 74, 86, 90, 100, 115, 120, 122, 140, 156, 170, 173, 174	16	16%	23%
Kneading		5, 7, 9, 13, 17, 28, 37, 58, 43, 47, 48, 77, 84, 96, 101, 105, 108, 110, 124, 135, 142, 150	22	22%	45%
Folding		3, 11, 12, 15, 19, 25, 26, 27, 30, 40, 42, 46, 60, 61, 63, 64, 66, 76, 109, 118	20	20%	65%
Lifting		21, 88, 93, 94, 104, 112, 117, 161, 167	9	9%	74%
Releasing		16, 22, 33, 41, 69, 83, 85, 96, 124, 128, 130, 132, 155, 160, 163, 166, 162, 167, 190, 195	20	20%	94%
Idle time		16, 24, 116, 135, 175, 186	6	6%	100%

According to the results obtained from the frame-by-frame analysis in GOMPLAYER, we were able to understand that the most frequent activities within the bakery process correspond to highly repetitive and physically demanding movements. The predominant action was kneading, accounting for approximately 22% of the total time, followed by folding, which represented around 20% of the workload. Subsequently, the activities of reaching and releasing occupied 16% and 20% respectively, while lifting, although less frequent at 9%, was the most physically demanding due to the weight handled. Some complementary activities, such as bending down or brief periods of idle time, represented smaller fractions of the workday. Therefore, we focused the analysis on the five main activities, as they

exceeded 10% of the working time and consequently contributed most significantly to fatigue and to the musculoskeletal disorders identified using the Marley and Kumar method, specifically the lifting element. These activities were evaluated using the REBA method

Table 6. Elements to be studied

Reaching	Kneading	Folding	Releasing	Lifting
				
16%	22%	20%	20%	9%

Bakery workers are constantly exposed to repetitive movements, load handling, awkward postures, and prolonged physical effort, all of which contribute to the development of various Cumulative Trauma Disorders (CTDs). Among the main disorders identified during the job evaluation, the following stand out:

Lateral epicondylitis occurs as a result of micro-tears in the extensor tendons of the forearm, caused by repetitive activities such as manual kneading, stretching large portions of dough, or holding heavily loaded trays. This disorder produces pain on the outer part of the elbow and weakness when gripping or lifting objects, directly affecting the worker's precision and functional strength.

Guyon's canal syndrome appears due to compression of the ulnar nerve at the wrist, often caused by repeatedly resting the hand on hard surfaces, prolonged use of rolling tools, or continuous carrying of heavy trays. Its main symptoms include tingling, loss of sensation, and weakness in the little finger and part of the ring finger, compromising grip stability.

Carpal tunnel syndrome (CTS) arises when pressure increases inside the carpal tunnel and compresses the median nerve. This condition is associated with repetitive wrist flexion, vibrations generated by certain equipment, and forceful grips during the handling of trays, molds, or dough. Workers report numbness, nighttime pain, reduced strength, and, in advanced cases, difficulty performing fine motor tasks.

De Quervain's tendinitis is associated with repetitive movements involving radial deviation of the wrist and intensive thumb use, especially during tasks such as cutting, portioning, or manipulating dough in fast and repetitive cycles. This disorder causes pain at the base of the thumb and limits its mobility, affecting precision and performance during product shaping.

Finally, low back pain is one of the most frequent problems in bakeries due to the bent postures adopted during manual kneading, repeated lifting of flour sacks, and handling trays from improper heights. The accumulated strain on the lumbar

region produces pain, muscle fatigue, and may progress to chronic injury if ergonomic improvements are not implemented in the workstation.

4.3 REBA evaluation

Each element studied, that is, each posture, was evaluated using the REBA, which was explained previously, below is an example of filling out this form, and then the level of risk that each element entails according to the method.

Table 7. Reaching risk evaluation

Rapid Entire Body Assessment (REBA)				Date: 22/11/2025	
Task: Reaching			Analyst: Emanuel Carrillo		
Group A		Group B			
Posture/Range	Score	Total	Posture/Range	Score	Total: Left and Right
Trunk		4	Upper Arms (Shoulders)		1 3
Upright	1	If back is twisted or tilted to side: +1	Flexion: 0-20°	1	Arm Abducted / Rotated: +1 Shoulder Raised: +1 Arm Supported: 0
Flexion: 0-20°	2		Extension: 0-20°	0	
Flexion: 20-60°	3		Flexion: 20-45°	0	
Extension: 0-20°	0		Extension: >20°	0	
Flexion: >60°	4		Flexion: 45-90°	1	
Neck		1	Lower Arms (Elbows)		1 2
Flexion: 0-20°	0	If neck is twisted or tilted to side: +1	Flexion: 60-100°	0	No Adjustments
Flexion: >20°	2		Flexion: <60°	0	
Extension: >20°	2		Flexion: >100°	1	
Legs		1	Wrists		1 1
Bilateral Wt Bearing: Walk, Sit	0	Knee(s) Flexion 30-60°: +1 Knee(s) Flexion >60°: +2	Flexion: 0-15°	0	Wrist Deviated / Twisted: +1
Unilateral Wt Bearing: Unstable	2		Extension: 0-15°	0	
Score from Table A		3	Score from Table B		1 4
Load / Force		1	Coupling		2 0
< 5 kg < 11 lb	0	Shock or Rapid Buildup: +1	Good	0	No Adjustments
5 - 10 kg 11 - 22 lb	1		Fair	1	
> 10 kg > 22 lb	2		Poor	2	
Score A [Table A + Load/Force Score]		4	Unacceptable		3
Activity		2	Score B [Table B + Coupling Score]		3 4
One or more body parts are static for longer than 1 minute	+1	Repeat small range motions, more than 4 per minute Rapid large changes in posture or unstable base	Score C (from Table C)		4 4
Activity	+1		Activity Score		2 2
Activity	+1		REBA Score [Score C + Activity Score]		6 6

Table 8. General risk results

Element	Score A	Score B		Score C	REBA Score	Risk level
		Left	Right			
Reaching	4	3	4	4	6	Medium
Kneading	7	2	2	7	8	High
Folding	3	6	6	5	7	Medium
Releasing	2	2	2	3	3	Low
Lifting	10	6	6	11	12	Very high

4.4 Workstation design and redesign

Before starting the redesign, we must begin to determine the appropriate working posture, the method proposed by Eastman Kodak Company was used as a reference. This method identifies the optimal posture by simultaneously comparing different task parameters. It functions like a “coordinate” system, where the intersection of two work factors indicates whether the activity should be performed sitting, standing, or in a combined posture.

In the case of bakery work, the activities require force application, variable tasks, and constant mobility, such as removing dough, preparing mixtures in the mixing machine, manually kneading, handling trays, and moving around the workspace. Due to the dynamic nature of these functions, the method recommends performing most of the work standing, since this posture facilitates quick transitions between activities and provides a wide range of motion to reach tools, materials, and equipment.

Likewise, the workspace is extended, meaning the worker must continually move to reach trays, access the mixer, or transfer products between stations. This reinforces the need to maintain an upright posture to allow efficient mobility and avoid awkward positions.

However, since the work shift lasts approximately 4 continuous hours, the Kodak method indicates that a seat should be available for active breaks, allowing the worker to alternate postural load and reduce fatigue. This alternation promotes muscle recovery and decreases the risk of musculoskeletal discomfort.

Finally, when combining variable tasks with repetitive movements once again, the recommendation remains to work standing, as this posture provides stability, facilitates repeated manual actions, and avoids movement restrictions that might occur when working seated.

After detecting the risk level of each element, the workstations were studied to determine what improvements could be implemented. Measurements were taken of the kneading table and one of the mixing machines to identify existing deficiencies.

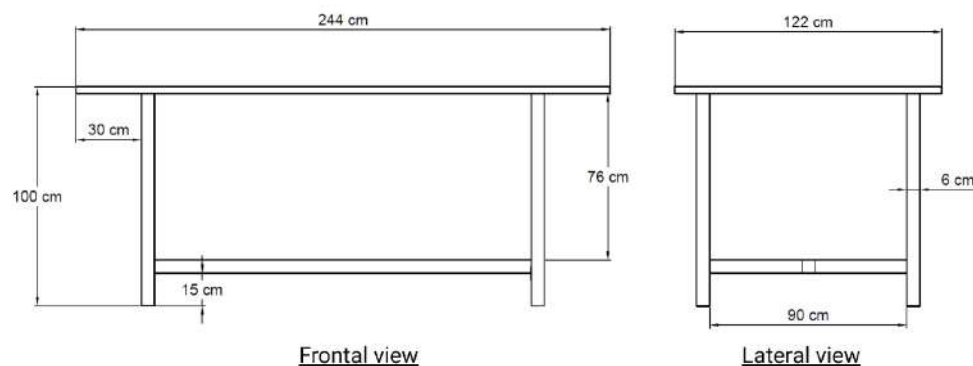


Figure 16. Current kneading table design

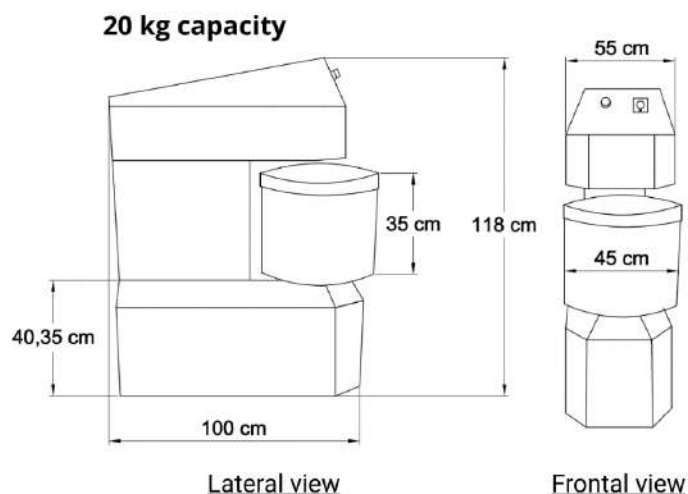


Figure 17. Current mixing machine design

Although the mixer has a capacity of 20 kg, in practice the workers handle an actual load of 13.2 kg, resulting from the following mixture:

Table 9. Mixture composition

Flour	8 kg
Water	4.8 kg
Salt	0.16 kg
Yeast	0.16 kg
Dough improver	0.08 kg
Total	13.2 kg

Although this load falls within the acceptable ranges established by NOM-036-1-STPS (20 kg), it is essential to consider that risk assessment is not based solely on weight but on the actual working conditions. In this process, handling the dough involves repeated lifting, postures that may not be fully neutral, and transporting the mixture from the mixing point to the kneading table.

When these actions are carried out continuously throughout the workday, the accumulated effort significantly increases the risk of physical fatigue, especially in activities where the distance traveled is constant and the posture does not allow for proper body mechanics.

Therefore, although the isolated weight does not exceed regulatory limits, the combination of repetitiveness, exposure time, postural demands, and movement turns this task into one with a higher ergonomic risk level, justifying the need for adjustments or controls to protect workers' health.

On the other hand, at the kneading table, although many work tools are within reach, some actions such as placing trays on high levels or transferring dough between stations require lateral stretching and shoulder elevation, increasing tension in the trapezius and deltoid muscles. Likewise, the absence of scheduled

breaks and the prolonged use of inclined postures prevent proper muscle recovery, contributing to accumulated fatigue.

The workspace also lacks elements that help reduce effort, such as an adequately designed workbench. The fixed table heights and the lack of forearm support increase strain on the upper limbs during kneading and folding. Additionally, based on the analysis of Mexican anthropometric percentile tables, we identified that the critical dimensions that must be corrected are: elbow height for force-intensive work, the ideal height for comfortable reach, the vertical distance from the elbow to the work surface, and the maximum safe lifting height from the floor.

Table 9. Body dimensions relevant to redesign (percentiles)

Workstation	Dimension	Design Principle	Range
kneading table	Elbow height (95th percentile male)	Design for the upper extreme to ensure that even taller individuals can work without shoulder elevation or forced posture.	113.5 cm
Functional reach at kneading table	Arm length (5th percentile male)	Design for the lower extreme to ensure that workers with shorter arms can reach the work area without excessive leaning or stretching.	82.6 cm
Safe handling height for mixing machine	Shoulder height (5th percentile male)	Design for the lower extreme to ensure all workers can reach controls without excessive arm elevation.	149.7 cm
Bending for mixing machine	Knee height (95th percentile male)	Design for the upper extreme to prevent taller workers from bending excessively.	55.3 cm
Minimum height of the mixing machine base	Instep height (95th percentile male)	Design for the upper extreme to avoid foot collisions and allow stable posture.	15.8 cm

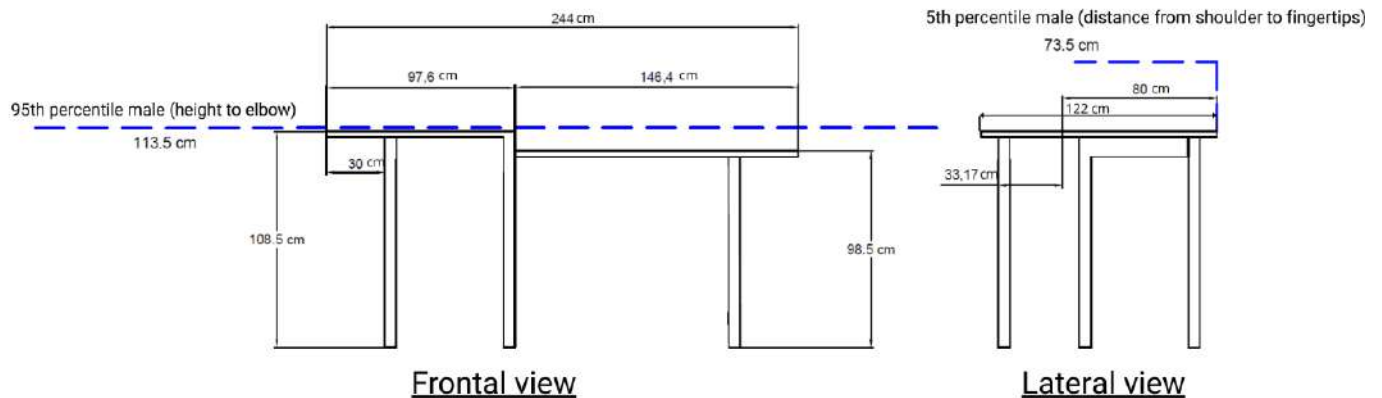


Figure 18. Redesign Kneading table

The redesign of the stepped worktable arose from the need to adapt the workstation to the physical demands specific to the bakery process and to the anthropometric characteristics of the workforce. The first modification involved incorporating a 108.5 cm surface, which was set 10 cm below the elbow height of the 95th percentile male (113.5 cm). This decision is based on the recommendations of *Ergonomic Design for People at Work* (John Wiley & Sons), which states that for tasks requiring force application such as weighing, kneading, and folding dough. The work surface should be positioned 10 to 20 cm below elbow height. This reduction helps decrease tension in the shoulder and trunk muscles, promoting a more neutral posture and reducing the risk of developing musculoskeletal disorders and cumulative trauma disorders (CTDs).

On the other hand, the second surface was kept at 113.5 cm, corresponding to the 95th percentile male's elbow height. This elevated section was designed for tasks involving arranging and distributing dough on trays, which do not require significant force. Keeping the surface at elbow height ensures a comfortable and stable posture, reducing shoulder elevation and facilitating precision during product placement.

Regarding the width of the table, an 80 cm section was incorporated, specifically designed to accommodate the maximum reach without leaning for the 5th percentile male, whose safe reach is 73.5 cm from the shoulder to the fingertips. This decision ensures that even workers with shorter arms can access tools, utensils, and dough without leaning or adopting awkward postures, promoting an efficient work zone with a lower ergonomic risk.

Finally, the 122 cm-wide section is justified as the space needed to distribute processed dough and organize additional tools, allowing activities that do not require constant manipulation to be performed outside the immediate reach zone, without interfering with the primary work area. This segment provides a spacious surface for placing trays, containers, or resting dough, increasing the operational functionality of the table while keeping the ergonomically critical zone clear. Likewise, this larger

section allows workers of different statures to use the secondary surface for complementary tasks without compromising body mechanics.

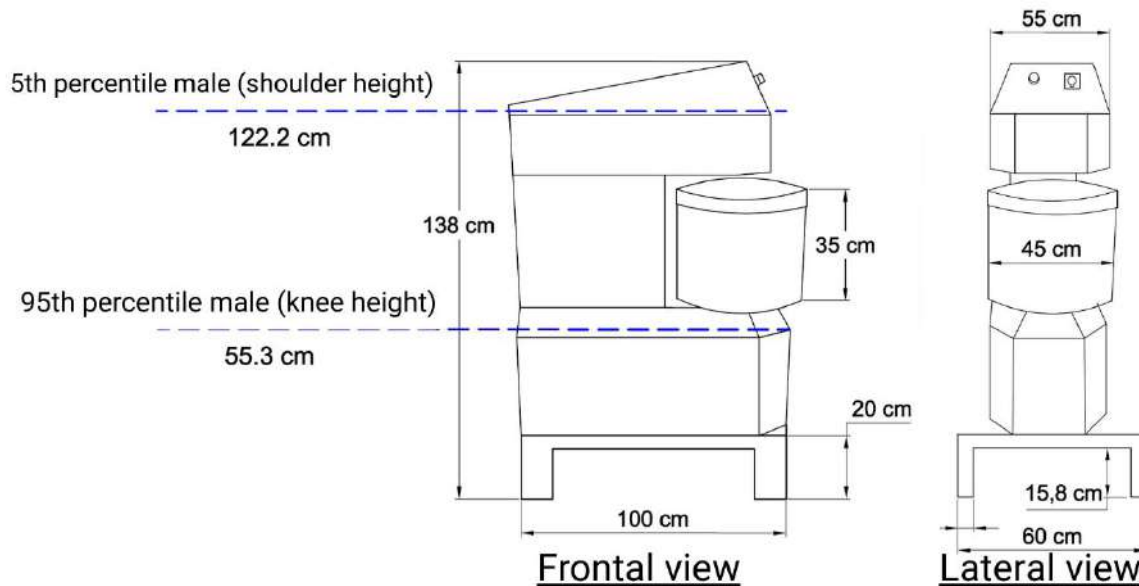


Figure 19. Redesign mixing machine

The identified problem is not solely related to the weight of the dough, but primarily to deficiencies in the design of the workstation. The low discharge height of the mixer forces the operator to excessively flex the trunk, the limited space makes proper frontal approach difficult, there are no ergonomic handles or containers for dough handling, and the horizontal distance at the start of the lift is greater than recommended. Together, these factors increase the biomechanical load on the lower back, contributing to fatigue, awkward postures, and a higher risk of musculoskeletal disorders.

Therefore, the ergonomic proposal focuses on redesigning both the physical environment and the worker's interaction with the mixer. The main improvement consists of elevating the discharge area using a sturdy metal base, ensuring that the discharge height falls within the safe range established by the ergonomic restriction: avoiding lifts above the shoulder height of the 5th percentile and below the knee height of the 95th percentile. Based on the analyzed anthropometric values, the current height (80.35 cm) must be raised approximately:

$$98.5 \text{ cm} - 80.35 \text{ cm} = 18.15 \text{ cm} \quad (1)$$

Rounded to 20 cm for construction practicality.

After this modification, the discharge opening is positioned at 100.35 cm, a functional height that allows the operator to remove and pour the dough from a neutral posture, avoiding trunk flexion and keeping the arms within a safe working range. This improvement provides an immediate advantage: the machine is aligned with an appropriate working height, allowing the operator to handle the dough without

bending and keeping the load close to the body, reducing the moment arm and consequently the lumbar effort.

Additionally, the proposal includes reorganizing the space around the mixer to enable a direct frontal approach, eliminating trunk rotation and ensuring stability during handling. A leveled, non-slip floor is also recommended to promote an adequate base of support during extraction tasks.

Finally, it is suggested to divide the dough into smaller loads whenever possible, reducing the individual lifting effort. Determined using the NIOSH lifting software.

4.5 Workplace layout

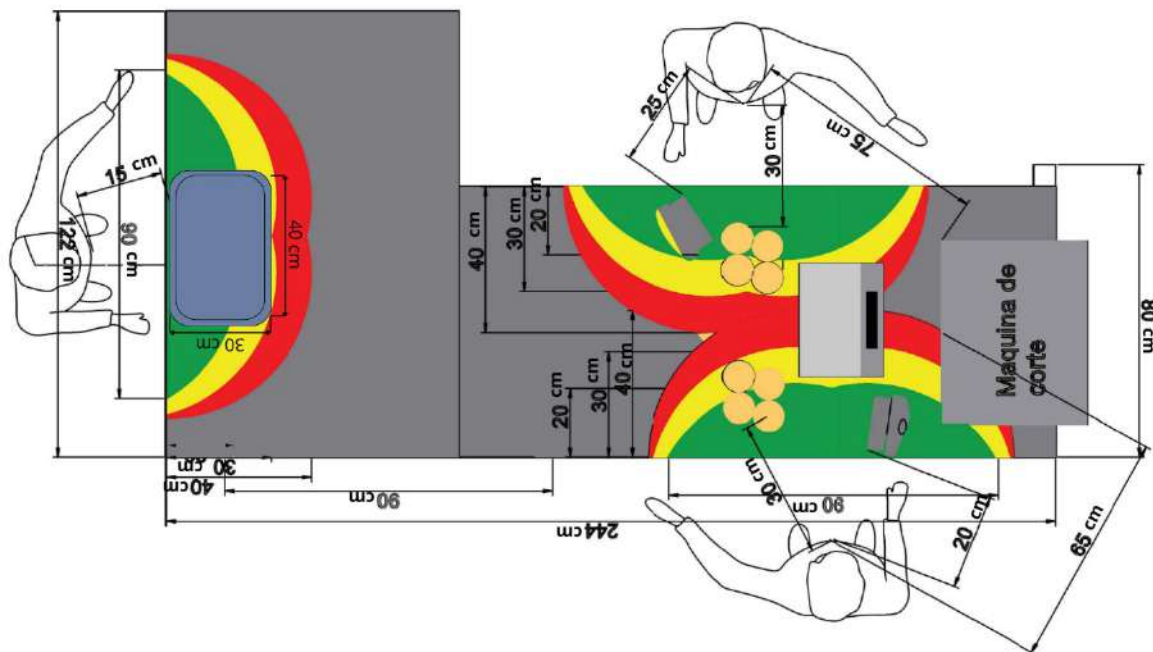


Figure 20. Workplace layout of kneading table

The redistribution of the workspace was designed by applying the Principle of Use, which states that objects or tools used most frequently should be placed closest to the worker. This criterion was combined with the reach analysis shown in the figure, where the green area corresponds to the minimum reach, the yellow area to the normal reach, and the red area to the maximum reach, which is associated with higher postural risk.

Under this principle, the main tools used in the process the ergonomic spatula, the scale, and the dough-cutting machine are used with different frequencies during dough preparation and portioning. The ergonomic spatula and the dough balls were placed within the green and yellow zones, since these elements are used the most, while the scale and the cutting machine were positioned in the maximum reach zone because they are not used as frequently during the workday. This arrangement allows the operator to access the most frequently used items without fully extending

the arms or excessively bending the trunk, significantly reducing fatigue in the shoulders, back, and neck.

The trays, which are used constantly but vary in weight depending on their contents, were also relocated according to this principle. The trays were placed within the normal reach zone. Their position was adjusted to keep them close to the body during handling and never within the maximum reach range.

This redistribution provides key ergonomic benefits:

- It reduces previously identified muscular tensions, especially in the shoulders, lumbar area, and upper extremities.
- It minimizes unnecessary movements, since frequently used tools remain within a safe and functional reach.
- It decreases the risk of long-term injuries by avoiding awkward postures, repetitive bending, or lifting from unsafe heights.
- It optimizes workflow, allowing quick transitions between weighing, cutting, and dough handling.
- It improves safety and efficiency by keeping the area organized and adapted to the worker's anthropometric limits.

4.6 Results of method NIOSH

It is essential to consider the 13.2 kg that workers handle when removing the dough from the mixing machine currently in use. To assess whether this weight falls within safe limits, the NIOSH-Metric software was used, which incorporates variables such as reach distances, lifting heights, frequency, posture angles, and exposure times. This analysis makes it possible to determine the Recommended Weight Limit (RWL) under the specific conditions in which the task is performed.

The study includes a comparison between the current workstation design and the proposed ergonomic design in order to identify improvements that reduce biomechanical load. If structural modifications cannot be implemented immediately, recommendations are also provided to adjust or reduce the handled weights, prioritizing the prevention of musculoskeletal disorders and cumulative trauma disorders (CTDs).

The dimensions, angles, and displacements used in the analysis were obtained from frames extracted using GOMPLAYER, complemented with measurements previously taken at the workstations. This combination of data ensures that the evaluation accurately represents the real conditions of the task and the physical impact on the worker.

Measure and Record Task Variables

Object Weight (kg) Average 13.2	Hand Location Origin (cm) Horizontal 20 Vertical 40.35	Hand Location Destination (cm) Horizontal 40 Vertical 100	Asymmetric Angle (degrees) Origin 45 Destination 45
Frequency Rate (Lifts/min) 2 <input checked="" type="text" value="1"/> .5 ≤ 2 or =.2	Duration (Hours) ≤ 1 or =1 ≤ 1 but ≤ 2 or =2 <input checked="" type="text" value="≤ 2 but ≤ 8 or =8"/>	Object Coupling Definition Good Fair <input checked="" type="text" value="Poor"/>	Goto Graphic help Clear Calculate

Figure 21. Demonstration of the NIOSH method (current design)

Determine the Multipliers and Compute the RWLs

Origin:	RWL=	HM	VM	DM	AM	FM	CM	
		23 * 1.00	* 1.00	* .9	* .86	* .75	* .90	=
		12.02 KG						
Destin:	RWL=	HM	VM	DM	AM	FM	CM	
		23 * .63	* .93	* .9	* .86	* .75	* .90	=
		7.04 KG						

Figure 22. Recommended Weight Limit (current design)

The recommended weight limit (RWL) of 7.04 kg indicates that the worker should only lift up to that amount to maintain an acceptable level of risk. Since the actual weight is 13.2 kg, nearly twice as much, the task does not meet ergonomic criteria, increasing the risk of injury. This difference also affects operational performance: because it requires greater physical effort, the worker's pace decreases, which increases cycle times, leads to longer waiting times between activities, and makes it more difficult to meet the established demand, as the task will likely become slower.

Measure and Record Task Variables			
Object Weight (kg) Average 13.2	Hand Location Origin (cm) Horizontal 20 Vertical 60.35	Hand Location Destination (cm) Horizontal 40 Vertical 98.5	Asymmetric Angle (degrees) Origin 45 Destination 45
Frequency Rate (Lifts/min) 2 <input checked="" type="text" value="1"/> .5 2.2 or =.2	Duration (Hours) 1 or =1 1 but <2 or =2 <input checked="" type="text" value="2 but <8 or =8"/>	Object Coupling Definition Good Fair <input checked="" type="text" value="Poor"/>	Goto Graphic help Clear Calculate

Figure 23. Demonstration of the NIOSH method (Redesign)

Determine the Multipliers and Compute the RWLs															
Origin:	RWL=	23	*	HM	*	VM	*	DM	*	AM	*	FM	*	CM	=
				1.00		1.00		.94		.86		.75		.90	
				12.55 KG											
Destin:	RWL=	23	*	HM	*	VM	*	DM	*	AM	*	FM	*	CM	=
				.63		.93		.94		.86		.75		.90	
				7.35 KG											

Figure 24. Recommended Weight Limit (Redesign)

At the destination, the redesign increases the RWL from 7.04 kg (original design) to 7.35 kg, meaning the worker can now handle a slightly heavier load under safer conditions. Although it still does not reach the actual 13.2 kg, this improvement shows that the ergonomic adjustments reduce risk and increase the safe lifting capacity compared to the original workstation.

4. CONCLUSIONS

The ergonomic evaluation showed that bakery work involves high physical, repetitive, and posture-intensive demands, which increases the risk of musculoskeletal injuries. Using the Marley and Kumar method, REBA, NIOSH, and frame-by-frame analysis, the main risk factors associated with kneading, shaping,

thermal handling, and load lifting were identified, demonstrating that many of these risks can be reduced through improvements in workstation design.

The proposed interventions such as elevating the mixer, reorganizing the work area, optimizing the distribution of tools, and improving load handling are feasible, low-cost, and can be implemented progressively. These adjustments reduce fatigue, improve posture, and increase safety without affecting productivity, and they can also be replicated in other bakeries with similar conditions.

Overall, the study confirms that ergonomics is essential for maintaining safe and efficient manual processes. When applied correctly, it not only reduces short- and long-term injuries but also improves performance, product quality, and the overall well-being of the workers who keep the artisanal bread-making tradition alive in Mexico.

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ERGONOMIC PROPOSAL OF THE TINNING AREA USING ANTHROPOMETRIC ANALYSIS AND NIOSH AND REBA METHOD.

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Resumen. El presente trabajo tiene como objetivo evaluar las condiciones ergonómicas del área de estañado en una maquila del sector electrónico, donde se identificaron posturas forzadas y riesgo de lesión lumbar durante el proceso de vaciado de barriles. Mediante el uso combinado del análisis antropométrico y del método NIOSH, se determinó la carga física asociada a la tarea y se propusieron mejoras orientadas a prevenir trastornos musculoesqueléticos. El estudio incluyó mediciones antropométricas de los operadores, registro fotográfico y aplicación del Mapa de Molestias Corporales (Marley & Kumar, 1996). Posteriormente, se aplicó la ecuación revisada de NIOSH (Waters et al., 1993) para calcular el Límite de Carga Recomendada (RWL) y el Índice de Levantamiento (LI), identificando niveles de riesgo moderados a altos. A partir de los resultados, se propuso un rediseño ergonómico de la estación de trabajo con ajuste de alturas, mayor área de maniobra y reducción del ángulo de flexión lumbar. La aplicación de la ergonomía industrial permitió disminuir el riesgo postural, mejorar la eficiencia del proceso y elevar la seguridad laboral de los trabajadores involucrados.

Palabras clave: ergonomía industrial, antropometría, análisis postural, prevención de riesgos, rediseño del puesto.

Relevancia para la ergonomía. Este trabajo aporta evidencia empírica sobre la aplicación de metodologías ergonómicas en un entorno industrial específico, integrando normas internacionales como la ISO 11226 y nacionales como la NOM-036-STPS-2018 para desarrollar un modelo de intervención replicable y adaptable a otras estaciones de trabajo con condiciones similares. La publicación de este estudio contribuye a sensibilizar al sector empresarial sobre la ergonomía como una herramienta estratégica que mejora el bienestar laboral, documentando con datos concretos la relación entre condiciones ergonómicas deficientes y afectaciones a la salud de los trabajadores.

Abstract. The objective of this work is to evaluate the ergonomic conditions of the tinning area in a maquila in the electronics sector, where forced postures and risk of lumbar injury during the barrel emptying process were identified. Through the

combined use of anthropometric analysis and the NIOSH method, the physical load associated with the task was determined, and improvements aimed at the prevention of musculoskeletal disorders were proposed. The study included anthropometric measurements of the operators, photographic recording, and application of the Body Discomfort Map (Marley & Kumar, 1996). Subsequently, the revised NIOSH equation (Waters et al., 1993) was applied to calculate the Recommended Load Limit (RWL) and the Lift Index (LI), identifying moderate to high risk levels. Based on the results, an ergonomic redesign of the workstation was proposed with height adjustment, greater maneuvering area, and reduction of the lumbar flexion angle. The application of industrial ergonomics made it possible to reduce postural risk, improve the efficiency of the process, and increase the occupational safety of the workers involved.

Keywords: industrial ergonomics, anthropometry, postural analysis, risk prevention, job redesign.

Relevance for ergonomics. This work provides empirical evidence on the application of ergonomic methodologies in a specific industrial environment, integrating international standards such as ISO 11226 and national standards such as NOM-036-STPS-2018 to develop an intervention model that can be replicated and adapted to other workstations with similar conditions. The publication of this study contributes to raising awareness in the business sector about ergonomics as a strategic tool that improves workplace well-being, documenting with concrete data the relationship between poor ergonomic conditions and effects on workers' health.

1. INTRODUCTION.

Ergonomics is a discipline that seeks to adapt spaces, tools, and tasks to the physical and cognitive capabilities of human beings, to optimize well-being and productivity (Kroemer & Grandjean, 2009). In the industrial context, its application is essential to prevent musculoskeletal injuries and improve operational efficiency.

In this project, it has been decided to focus the analysis on the tin-plating area within the maquila where one of the team members works, specifically on the workstation where the tin plating and barrel unloading process is carried out. The choice of this area responds to the identification of conditions that can affect the physical health of workers, particularly in relation to forced postures, repetitive movements, and musculoskeletal discomfort.

The tin-plating area, within the electronic manufacturing process, involves activities that demand significant physical effort and prolonged postures. In particular, the barrel unloading operation represents a critical point, as it requires repetitive bending and handling movements of loads up to 22.45 kg. These conditions, coupled with inadequate workplace design, increase the risk of developing musculoskeletal disorders in the lumbar region (Chaffin, 2005).

During the initial diagnosis, body discomfort surveys, direct observations, and photographic analysis of the postures adopted by the operators were applied. The

results showed that trunk flexion greater than 45° was maintained at more than 20% of the working time, exceeding the limit recommended by ISO 11226 (2000). Based on these findings, a detailed anthropometry study was developed and applied to the redesign of the station, and the NIOSH (1994) methodology was integrated to quantify the physical load and establish the biomechanical risk associated with the survey operations.

The main objective of this research was to evaluate the ergonomic conditions of the tinning area using quantitative tools, such as anthropometric analysis and the NIOSH method, to generate a proposal for improvement that reduces lumbar risk and optimizes the performance of operational personnel. This evaluation contributes to the practical application of the principles of NOM-036-STPS-2018, aimed at the prevention of ergonomic risk factors in the workplace.

1.1. Statement of the Problem.

1.1.1. Definition of the Problem.

The tin-plating area within the maquila represents a critical stage of the production process, in which working conditions have been identified that can compromise the physical health of workers. In particular, the workstation where the process is carried out presents ergonomic risks arising from forced postures, repetitive movements, and continuous physical efforts.

This project arises as a proposal for improvement, not only to highlight the existing problems, but also to offer practical and applicable solutions that contribute to the well-being of operators. As it is an environment close to a team member, there is the opportunity to intervene directly in the improvement of working conditions, promoting a safer, more efficient, and healthier space.

The definition of the problem focuses on the need to evaluate and optimize the ergonomic conditions of this specific station, to reduce musculoskeletal discomfort and improve the quality of work life of those who perform these functions continuously.

1.2. Justification.

This project arises from the need to improve working conditions in the tin-plating area of a maquila, where ergonomic risk factors have been identified that directly affect the physical well-being and performance of the workers. Through the analysis of the work environment and the application of principles of industrial ergonomics and anthropometry, it seeks to develop an intervention proposal that responds to the real demands of the process and those who execute it.

The justification for the design is based on the following benefits:

- Reduction of musculoskeletal risks: By adapting the workplace to the anthropometric characteristics of the operators, exposure to forced postures, repetitive movements, and unnecessary efforts is reduced.

- Improved operational performance: A more comfortable and functional environment promotes concentration, precision, and efficiency in tasks, which can translate into higher productivity and lower error rates.
- Increased job satisfaction: By meeting the physical and operational needs of female workers, a healthier, more inclusive, and motivating environment is promoted.
- Fulfillment of strategic objectives: The design proposal aligns with the objectives of the project by integrating real data, analysis tools such as the Body Map, and technical principles that allow each improvement to be justified from a functional and human perspective.

Overall, the design not only represents a technical solution but also a commitment to the dignity of work, the prevention of injuries, and the optimization of the production process.

1.3. Project Objectives.

1.3.1. General Objective: To analyze the barrel unloading process in the tin-plating area, applying principles of industrial ergonomics and anthropometry, to identify musculoskeletal risks and propose improvements that reduce the physical load and favor the health of workers.

1.3.2. Specific Objectives:

- Detect and evaluate the ergonomic risks present in the unloading process, using analysis tools such as direct observation and the Body Map, to obtain a clear diagnosis of the current situation.
- Formulate ergonomic intervention proposals based on principles of industrial ergonomics and anthropometry, aimed at improving work postures, reducing physical fatigue, and preventing possible musculoskeletal injuries.
- Recommend ergonomic adjustments in the distribution of space, the height of the emptying tub, lighting, and furniture, to promote adequate postural conditions and reduce the physical effort of operators.

1.4. Delimitations.

This project will focus only on the tin-plating area within the maquila where our colleague Sarahi works, specifically on the workstation where the tin-plating process and the subsequent unloading of the barrel are carried out.

The analysis will be limited to the ergonomic conditions of two workers who perform these operations continuously, considering their postures, repetitive movements, and physical discomfort reported through the application of the Body Discomfort Map (Marley & Kumar, 1996).

The scope of the study will cover:

- Direct observation of the activities at the selected workstation.
- The identification of ergonomic risks may lead to musculoskeletal discomfort.

- The analysis of the surveys was applied to detect the areas of the body with the greatest discomfort.
- The proposal of ergonomic improvements that contribute to reducing the physical load of workers during the unloading of the barrel.

The project will not include other areas of the maquila, nor workers outside the tin-plating process. Environmental factors such as lighting, noise, or temperature will not be covered either, since the main objective is to assess the postural and physical risks in the task.

2. METHODOLOGY.

This second breakthrough focuses on the application of anthropometry principles to optimize the tin-plating area, specifically in the barrel unloading process. From the postural analysis performed in Avance I, a critical posture of prolonged lumbar flexion greater than 45°, maintained for 150–200 seconds per shift, and associated with a level of discomfort of 8/10 in the lumbar region, was identified. This condition represents a significant ergonomic risk according to ISO 11226.

The main objective of this advance is to eliminate this posture by redesigning the workstation, adjusting its dimensions to the real anthropometric characteristics of the operators. To this end, a detailed study of the postures adopted was carried out, critical body measurements were identified, and improvements were proposed based on standardized anthropometric data. The redesign seeks to reduce flexion time to less than 30 seconds per shift, maintain posture within the safe ergonomic range (<20° flexion), and improve comfort, safety, and operational efficiency.

2.1 Description of the work process.

The tinning area is part of the manufacturing process of electronic components known as discrete (photological, maxial, miniaxial, OPBS and OPBMini). At this stage, operators coat the metal frames with tin to ensure electrical conductivity and facilitate subsequent welding.

During the barrel unloading operation, the worker empties the containers with already treated parts into a rinsing and separation vat. Each barrel can reach an average weight of 20.35 kg dry and 22.45 kg when wet, and this activity is repeated approximately 10 times per shift.

Despite having a transport trolley, the emptying vat is at an insufficient height, which forces the operator to tilt the trunk more than 45°, extending the arms forward to handle the load. This posture generates lumbar tension, fatigue, and risk of musculoskeletal injury, especially in the L4-L5-S1 region, according to observations and photographic records of the area.

The analysis was carried out based on the guidelines of NOM-036-STPS-2018 and ISO 11226 (2000), which establish the safe bending limits and the criteria for evaluating static and dynamic work postures.

2.2 Application of anthropometric analysis.

2.2.1. Introduction to anthropometry.

Anthropometry is a fundamental tool in ergonomic design, as it allows spaces, equipment, and tools to be adapted to the physical characteristics of the user, avoiding forced postures, overexertion, and repetitive movements (Panero & Zelnik, 2014).

Its application in industrial environments contributes to the optimization of performance and the prevention of musculoskeletal disorders by ensuring that the dimensions of the job are adjusted to the profile of the working population (Kroemer & Grandjean, 2009).

This advance describes the application of anthropometric data in the tin-plating area, focusing on the barrel unloading process. Through the analysis of relevant body dimensions and design principles, the optimal ergonomic configuration for the station was determined, considering the measurements of the target population and the demands of the task.

2.3. Literature review.

2.3.1. Theoretical aspects of anthropometry.

Industrial anthropometry comprises the systematic measurement of the physical dimensions of the human body in order to design workstations, tools, and equipment adapted to the worker (Tilley, 2002). Anthropometric data are grouped into percentiles, which allow the majority of the population to be covered according to their variations in size, sex, and age. Anthropometric dimensions are classified into two main types:

- Static dimensions: They are obtained with the body in a fixed position, such as height, elbow height, shoulder width or knuckle height.
- Functional dimensions: These are measured during movement or in specific tasks, such as frontal functional range or depth of maneuver.

According to Grandjean & Kroemer (1997), the application of anthropometric measurements in industrial design must follow three fundamental principles:

- Design for extremes: Low percentiles (P5) are used to define minimum ranges and high percentiles (P95) to ensure sufficient space, guaranteeing coverage for 90% of the population.
- Adjustable design: Mechanisms are incorporated that allow the workstation to be adapted to different users, such as lifting platforms or adjustable surfaces.
- Average design: It is based on average population values, although its coverage is limited and may exclude users from the extremes.

The present study adopted the principle of adjustability, since the workstation is used by operators of different heights and body proportions.

2.3.2. Importance of anthropometric application.

Ergonomic design based on anthropometry is key to reducing the risk of injury and improving worker comfort. According to the Eastman Kodak Company (2003), poor adaptations between the job and the user are one of the main causes of fatigue, discomfort, and decreased work performance.

NOM-036-STPS-2018 establishes that the adequacy of spaces must be based on verified anthropometric measurements, especially in tasks that involve physical effort or handling of loads.

The application of anthropometry in workstation design has multiple benefits:

- Prevention of musculoskeletal injuries: By avoiding awkward postures and repetitive movements outside the safe range.
- Reduced discomfort and fatigue: By allowing the body to work in natural, balanced positions.
- Improved operational efficiency: By facilitating access, visibility and handling of loads.
- Inclusion of body diversity: When designing for a wide range of heights, reaches, and proportions.

In this project, anthropometry was used as a technical tool to transform a high-risk workstation into an ergonomically optimized station, basing each decision on objective data and universal design principles. In this context, the application of anthropometry in the tin-plating area made it possible to determine the necessary adjustments in height, reach, and depth of the emptying vat, so that workers maintain safe and functional postures during their day.

2.4. Development.

2.4.1. Anthropometric sources of information used.

To support the ergonomic redesign of the tin-plating area, reliable and standardized anthropometric sources were used to cover a wide range of body characteristics in the working population. The main sources used were:

- Human Factors and Ergonomics Society (2022). Updated database with percentiles by sex and age.
- NASA Anthropometric Source Book (1978). Classic reference for technical and spatial design.
- Eastman Kodak Company (Champney, 1975; Muller-Borer, 1981). Tables applied in industrial design.
- Panero & Zelnik (2014). The human dimensions in interior spaces.
- Tilley (2002). The Measure of Man and Woman.
- ISO 11226 (2000). Safe posture limits and trunk flexion criteria.

These sources allowed for the selection of critical body dimensions, the definition of appropriate percentiles, and the application of ergonomic design principles with technical support. These sources were selected for their validity, scientific support, and applicability to industrial ergonomic design.

2.5. Analysis of the work.

The analyzed activity consists of the manual unloading of tinning barrels, with an average weight of 22.45 kg, which are poured into a rinse vat. During the observation, it was recorded that the operator maintained a lumbar flexion greater than 45°, combined with arm extension and trunk rotation. These postures were documented in a sequence of frames.

A detailed study of the barrel emptying process was carried out, using frames and direct observation to identify risk positions. More than 100 representative frames were documented, classifying postures by frequency and ergonomic risk, which allowed prioritizing redesign interventions.

Table 1. Frame Table

Posture	Image	No. Frame	Frequency	% Frequency	Cumulative Frequency
Downward bending of the neck, arms extended or unsupported, and possible deviation of the wrists.		113, 117, 120, 122, 125, 127, 131, 133, 134, 139, 141, 142, 143, 144, 145, 148, 149,	36	36%	36%

		151, 152, 157, 158, 159, 161, 162, 166, 168, 169, 170, 172, 177, 178, 179, 182, 183, 188, 189			

Trunk flexion.		2, 3, 5, 6, 8, 12, 14, 16, 17, 20, 22, 24, 26, 27, 29, 30, 31, 32, 36, 37, 38	21	21%	57%
Downward bending of the neck, arms extended or unsupported, and possible deviation of the wrists.		52, 53, 54, 55, 56, 79, 80, 81, 83, 84, 86, 87, 88, 90, 97, 99,	16	16%	73%

Slanted neck, outstretched arms, and possible deviation when handling			39, 40, 41, 44, 45, 47, 65, 67	8	8%	81%
Static standing posture with unilateral leg flexion to operate a lever			101, 102, 104, 105, 106, 109, 112	7	7%	88%
Manual loading without ergonomic support.			190, 191, 192, 197, 200	5	5%	93%

Handling loads without proper support			58, 59, 60, 62	4	4%	97%
Trunk bending and load handling at uncomfortable heights.			49, 50, 51	3	3%	100%

2.6. Definition of relevant body dimensions.

The ergonomic redesign of the workstation in the tin-plating area was based on the identification and application of key body dimensions that directly influence operator posture, reach, comfort, and safety. The six dimensions selected as critical to the design are described below:

Elbow height in a standing position is the vertical distance from the ground to the elbow point when the arms hang relaxed. This dimension defines the optimal height of the top edge of the emptying vat. If the tub is below this height, the operator is forced to flex the spine; if it is above, tension is generated in the shoulders.

The front functional reach represents the maximum horizontal distance that a person can comfortably reach to the front without tilting the trunk. This measurement determines the maximum safe depth of the tub. Excessive reach underload increases the moment of force on the spine.

The knuckle height corresponds to the distance from the ground to the knuckles when the arms hang naturally. This dimension establishes the minimum comfortable height for cargo handling. If the base of the tub is below this value, the flexion of the trunk increases, and tension is generated in the lower back.

Shoulder width measures the distance between the ends of the deltoids. This dimension is essential to define the minimum lateral space necessary for safe maneuvers.

Body depth (thorax) is the distance from your chest to your back in an upright position. This measure allows the clearance to be established in front of the operator, avoiding contact with edges and allowing a relaxed posture.

Finally, total height is the height from the ground to the top of the head. This dimension was used to verify that all elements of the workstation (controls, visibility, accesses) are functional for the height range.

These dimensions were selected for their direct impact on the biomechanics of work and their relevance to the redesign of the station. Its application allows the work environment to be adapted to the real characteristics of users, reducing ergonomic risks, improving operational efficiency, and promoting occupational health in the long term.

The anthropometric dimensions selected for the redesign are shown in the following table:

Table 2. Anthropometric dimensions

Body Dimension	Applied Percentile	Value	Use in Design
Elbow Height (Standing)	5F – 95M	37 – 45.1 in	Define the optimal height of the top edge of the emptying vat and whether there will be column bending during emptying.
Front functional scope	5F – 95M	26.1 in – 33.9 in	Establishes the maximum safe depth of the tub and prevents overextension of loaded arms.
Knuckle Height	5F – 95M	26 in – 32.2 in	Determines the minimum height of the tub base and ensures the comfort zone for load handling.
Shoulder width (bideltoid)	5F – 95M	15.3 in – 20.1 in	It defines the minimum width of the maneuvering area and ensures sufficient space for lateral movement.
Body depth (chest)	5F – 95M	8.3 in – 11.9 in	It establishes the free space around the stall, prevents

			contact with edges, and allows postural changes.
Overall height (height)	5F – 95M	59.5 in – 73.5 in	Verify vertical scopes and visibility to ensure all controls are accessible.

The selected values guarantee coverage of 90% of the working population, following the criteria of industrial anthropometric design (Tilley, 2002; HFES, 2022).

2.7. Anthropometric principles applied.

The ergonomic design based on anthropometry is based on principles that allow workspaces to be adapted to the physical characteristics of the users. The following were applied for in this project:

- Design for extremes: This principle is used when one dimension must accommodate the entire population. The most restrictive percentile is selected:
 - For reach dimensions (such as tub depth or handling height), the female P5 is used, which represents people with smaller stature or arm length.
 - For space dimensions (such as maneuvering width or frontal depth), the male P95 is used, which represents people of greater build.
- Adjustable design: The possibility of modifying certain dimensions of the workstation to adapt to different operators is incorporated. In this case, a lifting platform with an adjustment range between 35.4 and 43.3 inches was proposed, allowing the height of the tub to be adapted to each user during shifts.
- Average design (not applied): Although common in environments with low ergonomic risk, this principle was discarded in this project due to the need to cover population extremes and prevent injuries.
- Functional accessibility, by reducing the depth of the tub to keep the range within the safe range. Controls and handling areas should be within the comfortable maximum reach without excessive arm extension (up to 65% of total reach). (Panero & Zelnik, 2014).

The application of these principles ensures that the redesign is inclusive, functional, and safe for most operators, reducing postural risks and improving operational efficiency.

2.8. Selection of suitable percentiles.

The analysis determined that the optimal design should be based on the **female 5th percentile** for reaches (to avoid overextensions) and the **male 95th percentile** for heights (to avoid restrictions). This configuration allows for a **universal adjustable range**, in line with the Eastman **Kodak Company's (2003) recommendations** for mixed industrial stations.

The percentiles selected for each dimension are detailed below:

Table 3. Percentile Selection

Elbow Height (Standing)	Define the optimal height of the tub rim	P5 Women / P95 Men	37in / 45.1 in
Front functional scope	Sets the maximum safe depth of the tub	Women's P5	26.1 in
Knuckle Height	Determines the minimum comfortable height for load handling	Women's P5	26 in
Shoulder width	Define the minimum width of the manoeuvring area	P95 Male + 35% Slack	20.1 in
Body depth (chest)	Set the front clearance	P95 Male	11.9 in
Total height	Verify accessibility and visibility of the position	P5 Women / P95 Men	59.5 in / 73.5 in

This selection allows the redesign to be functional for people of different sizes, avoiding exclusion for physical reasons and promoting equity in the work environment.

2.9. Partial conclusions.

Anthropometric analysis allowed the workstation to be adapted to the physical characteristics of the operators. North American anthropometric tables standardized by the Human Factors and Ergonomics Society (2022), based on Panero & Zelnik (2014) and Tilley (2002), were used.

Critical dimensions considered included elbow height, frontal functional reach, knuckle height, shoulder width, body depth, and total height. The principles of design for extremes and adjustability were applied, with the aim of covering 90% of the working population, from the 5th percentile female to the 95th percentile male (Tilley, 2002).

By using standardized anthropometric sources and selecting six key body dimensions (elbow height, frontal functional reach, knuckle height, shoulder width, chest depth, and total height), a technical solution was designed that responds to the real characteristics of the operators. The application of the principles of design for ends and adjustable design made it possible to cover 90% of the working population, guaranteeing functionality, safety, and comfort.

The redesign included lifting the tub, adding an adjustable platform, expanding maneuvering space, and relocating the shuttle cart. These modifications make it possible to maintain posture within the safe ergonomic range (<20° flexion),

reduce flexion time to less than 30 seconds per shift (–85%), and reduce the level of lumbar discomfort to $\leq 2/10$.

In conclusion, this breakthrough demonstrates that the rigorous use of anthropometric data and ergonomic principles can transform a high-risk work environment into a functional, inclusive, and safe workstation. In addition, it lays the foundations for future interventions in other areas of the production process, promoting occupational health, operational efficiency and user-centered design.

3. ANALYSIS OF WORK POSTURES.

3.1. Introduction.

Workplace ergonomics focuses on analyzing the interactions between the worker, tools, the physical environment, and task conditions. Its purpose is to optimize human performance, prevent musculoskeletal injuries, and improve occupational safety and well-being (Kroemer & Grandjean, 2009).

In this advance, the postures adopted by the operators of the tin-plating area, the physical space available, the tools used, and the associated ergonomic risks are analyzed. In addition, the application of the NIOSH and REBA method to evaluate the physical load during the handling of the tin barrels is presented, as well as the proposal for ergonomic redesign based on the results obtained.

3.2. Literature review.

3.2.1. Theoretical aspects of work postures.

Work postures represent the way the body positions itself to execute a task, and their correct evaluation is essential to prevent injuries. According to ISO 11226 (2000), prolonged static postures and trunk flexions greater than 45° should be avoided, as they generate overload in the lumbar region.

Grandjean & Kroemer (1997) mention that prolonged standing postures increase pressure in the lower back and reduce blood circulation, while sitting postures without adequate support cause tension in the cervical area. Therefore, the design of the position must allow alternation between both postures (mixed) and offer support or rest options.

According to the Eastman Kodak Company (2003), proper work posture is critical to maintaining worker efficiency, productivity, and health. There are three main types of work posture:

1. Sitting posture:

- Work carried out mainly from a seat with support.
- Body weight transferred through the ischial tuberosities.
- It reduces energy expenditure by 10% compared to standing.
- Disc pressure increases 40% compared to the standing posture.

2. Standing Posture:

- Work done in an upright position with no seating support.
- Body weight is supported by both feet.
- Increased mobility and ability to generate force.
- Increased energy expenditure and fatigue in the lower extremities.

3. Mixed Posture:

- Alternating between sitting and standing.
- Use an adjustable Workstation.
- Reduces negative effects of prolonged static postures.
- Allows physiological recovery without interrupting productivity.

In the tin-plating area, it was identified that the emptying operation is performed completely standing, with trunk flexion and arm extension, which represents a moderate to high ergonomic risk.



Figure 1. Main risk frame

3.3. Theoretical aspects of the distribution of the work area.

The distribution of the work area directly influences the efficiency and comfort of the worker. According to Eastman Kodak Company (2003), efficient design should ensure:

- Accessibility: All work items must be within functional reach of the operator.
- Visibility: Optimal visual angle between 0-30° below the horizontal line.
- Freedom of movement: Enough space for postural changes and movements.
- Reach zones:
 - Primary Zone (Frequent Use): 14-16" radius
 - Secondary Zone (Occasional Use): 20-24" radius

In the area analyzed, the original layout had space limitations and interference zones between the operator, the barrels, and the emptying vat. The proposed redesign seeks to improve workflow, reduce unnecessary movements, and facilitate ergonomic posture.



- Low back pain: Pain in the lumbar region due to overload.
- Tendonitis: Inflammation of tendons due to repetitive movements.
- Carpal tunnel syndrome: Compression of the median nerve.
- Bursitis: Inflammation of the synovial bursa.
- Epicondylitis: Inflammation at the insertion of elbow tendons.

- Cause: Sustained flexion of the neck during emptying

- Affected area: Trapezius and sternocleidomastoid muscles
- Severity: Moderate

4.2. Workstation Assessment Application to Detect Potential Risk Factors

The Body Discomfort Map (Marley & Kumar, 1996) was applied to two operators in the tinning area. The results showed:

Survey 1:

- Lower Back: 8/10 (critical)
- Shoulders: 5/10 (moderate)
- Neck: 2/10 (mild)
- Legs: 0/10 (null)

Survey 2:

- Lower back: 8/10 (high)
- Shoulders: 5/10 (moderate)
- Arms: 2/10 (light)
- Hands/wrists: 0/10 (null)

The area of greatest discomfort coincides with the lumbar region, validating the need for urgent ergonomic intervention.

4.3. Identification of Risk Factors in the Task.

Through photographic analysis of 100 frames, the following risk factors were identified:

Table 4. Risk factors

Risk Factor	Frequency	% of Time	Risk Level
Trunk flexion >45°	21 frames	21	Critical
Neck flexion + arms extended	52 frames	52	High
Trunk rotation	8 frames	8	Moderate
Unsupported manual loading	5 frames	5	Moderate

Critical Finding: Trunk flexion >45° is maintained 21% of the working time, exceeding by 720% the limit recommended by ISO 11226 (2000), which establishes a maximum of 2.5% of the time. These factors coincide with the risk criteria established in NOM-036-STPS-2018 for tasks with manual handling of loads.

Table 5. Ergonomic risk factors identified in the task.

Factor	Present Value	Consequences	Impact
Improper height of the emptying vat	59.7 inches from the floor	Forces bending of the trunk >45° during emptying	Generates load in the lumbar region (L4-L5-S1)
Excessive distance from cart to tub	40 in	Requires loaded arm extension (49.5 lbs.)	Increases the moment of force on the spine
Very low tub top edge	36.7 in	Does not allow forearm support during emptying or controlled technique	Increases the risk of splashes
Limited maneuvering space	7.8 ft ²	Insufficient for optimal operator positioning	It makes it difficult to change posture during the task and increases the risk of tripping.

In the tin-plating area:

- The barrels lack ergonomic handles.
- Smooth and slippery surface makes it difficult to grip.
- Weight of 49.5 lbs. exceeds the recommended limit for frequent lifting.

5. ERGONOMIC RISK ASSESSMENT.

5.1. Application of the NIOSH Method.

To quantify the biomechanical risk associated with lifting barrels, the NIOSH (National Institute for Occupational Safety and Health) Revised Equation was applied, which allows the risk of lumbar injury associated with manual lifting of loads to be assessed by calculating the Maximum Recommended Weight (RWL) and the Lifting Index (LI).

$$\text{Formula: } RWL = HM \times VM \times DM \times CM \times FM \times AM \times LC \quad (1)$$

The following variables were recorded during field observation:

Table 6. Variables measured in the tin-plating area.

Variable	Description	Observed Value
H (Horizontal Distance)	Distance from ankles to hands	15.74 in
V (Vertical Distance)	Initial height of the hands from the ground	25 in

D (Vertical Travel Distance)	Difference Between Origin and Destination of the Survey	20 in
A (Angle of Asymmetry)	Trunk rotation during emptying	30°
F (Lifting Frequency)	10 lifts per shift (approx. 1.25/hour)	Low
C (Grip Condition)	Regular (metal barrel without handles)	0.95
LC (Constant Load)	NIOSH Base Value	51 lb

Multiplier Calculation:

1. HM (Horizontal Multiplier): $HM = 10/H_{(2)} = 10/15.74 = 0.63$
2. VM (Vertical Multiplier): $VM = 1 - (0.0075 \times |V - 30|)_{(3)} = 1 - (0.0075 \times 5) = 0.96$
3. DM (Distance Multiplier): $DM = 0.82 + (1.8/D)_{(4)} = 0.82 + (1.8/20) = 0.91$
4. AM (Asymmetric Multiplier): $AM = 1 - (0.0032 \times A)_{(5)} = 1 - (0.0032 \times 30) = 0.90$
5. FM (Frequency Multiplier): For low frequency ($<0.2/\text{min}$), duration >1 hour₍₆₎ = 0.95
6. CM (Coupling Multiplier): Regular grip₍₇₎ = 0.95

Results:

$$RWL = 0.63 \times 0.96 \times 0.91 \times 0.95 \times 0.95 \times 0.90 \times 51 \approx 23.52 \text{ lb}$$

Lift Index (LI):

$$LI = \text{Actual Weight} / RWL_{(8)} = 49.5 \text{ lb} / 23.52 \text{ lb} = 2.10$$

Interpretation according to NIOSH (1994):

- $LI \leq 1.0$: Low Risk (Safe)
- $1.0 < LI \leq 3.0$: Moderate-high risk (some workers will experience problems)
- $LI > 3.0$: High risk (most workers will experience problems)

Applying the corresponding multipliers, the result was an RWL. The actual weight handled is 49.5 lbs. which exceeds the recommended limit, generating a lift index (LI) = 2.10, indicating a $\approx 23.52 \text{ lb}$ moderate-high ergonomic risk of lumbar injury according to NIOSH criteria and requiring immediate ergonomic intervention.

This result confirms that the task requires urgent redesign, since the current conditions exceed the safe physical capacity of most operators and could cause lumbar injuries due to accumulated mechanical overload.

Critical factors identified:

1. Excessive horizontal distance (0.63): Reduces capacity by 37%.
2. Angle of asymmetry (0.90): Trunk rotation increases risk.
3. Inadequate height (0.96): Sub-optimal position for lifting.

5.2. Application of the REBA Method.

The REBA (Rapid Entire Body Assessment) method assesses whole-body postural risk by considering forced postures, muscle load, and type of activity.

Posture Analyzed: Barrel discharge into the emptying tub.

Table 7. Group A (Trunk, Neck, Legs):

Segment	Position	Scoring
Trunk	Flex >60°	4 points
	Torque	+1 point
Collar	Flex 20-45°	2 points
Legs	Bilateral support, knees bent 30-60°	2 points

Subtotal Group A: $4 + 1 + 2 + 2 = 9$ points Table A: Score = 8 + Load/Strength:
Load between 11-22 lbs (22.45 kg = 49.5 lbs) = +2 points Total Group A: 10 points

Table 8. Group B (Arms, Forearms, Wrists):

Segment	Position	Scoring
Arms	Elevation 45-90° + abduction	3 + 1 = 4 points
Forearms	Flexion >100°	2 points
Dolls	Flexion/extension >15° + torsion	2 + 1 = 3 points

Subtotal Group B: $4 + 2 + 3 = 9$ points Table B: Score = 8 + Grip Quality: Regular = +1-point Total Group B: 9 points

Final REBA Score:

- Table C (Group A + Group B) ⁽⁹⁾: 11 points
 - Activity: Repetitive movements >4 times/min = +1 point
- TOTAL REBA: 12 points

Interpretation according to REBA:

- 1 point: Negligible risk
- 2-3 points: Low risk
- 4-7 points: Medium risk
- 8-10 points: High risk
- 11-15 points: Very high risk (intervention necessary)

REBA Conclusion: With a score of 12 points, the task presents a very high risk. Immediate intervention and urgent ergonomic changes are necessary.

Table 9. Comparison of Methods:

Method	Result	Risk Level	Action Required
NIOSH	LI = 2.10	Moderate – High	Intervention Needed
REBA	Very High (12 pts)	Moderate – High	Intervention Needed

Both methods coincide in the urgent need for ergonomic redesign of the workplace.

6. DESCRIPTION OF HAND TOOLS USED.

Current Tools:

1. Metal Barrels:
 - Material: Stainless Steel
 - Capacity: 50 lbs. of components
 - Empty weight: 35.71 lb
 - Wet Loaded Weight: 49.5 lbs
 - Problems identified:
 - No ergonomic handles
 - Smooth and slippery surface
 - 18" diameter makes it difficult to grip
 - High center of gravity when full
2. Transport Cart:
 - Material: Metal frame with wheels
 - Function: Reduce effort when transporting kegs
 - Problems identified:
 - Fixed height not adjustable
 - No safety brake
 - Excessive distance (15.7 in) from the tub
3. Emptying Tub:
 - Material: Stainless Steel
 - Current Depth: 21.7 in
 - Edge Height: 18.9 in from the floor
 - Problems identified:
 - Inadequate height (forces bending >45°)
 - Excessive depth (requires arm extension)
 - No forearm support edges

Recommendations for Improvement:

1. Barrel Redesign:
 - Incorporate ergonomic side handles at 90° and 180°
 - Non-slip textured surface
 - Handle Diameter: 1.5-2" for optimal grip
 - Fill level indicators (75% maximum)
2. Cart Upgrade:
 - Adjustable Lift System (35.4-43.3 in)
 - Safety brake on wheels
 - Reduce cart-tub distance to a maximum of 5.9 in
 - Add Positioning Guides
3. Tina Redesign:
 - Adjustable Edge Height: 18.5-26.4 in

- Reduce depth to 16.9 in
- Rounded edges with forearm support
- Improved drainage system

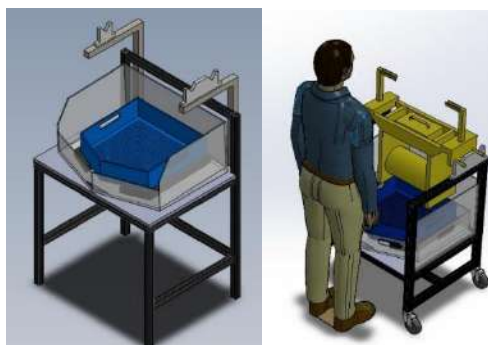


Figure 3. Recommendations for improvement

7. DESCRIPTION OF THE SELECTED WORK POSTURE.

The results showed that the emptying operation is performed standing, with partial support on the feet and slight bending of the knees. However, the deficient height of the tub forces you to maintain a static posture with prolonged lumbar flexion and downward inclination, which increases the effort in the lumbar and cervical areas.

According to the Eastman Kodak Company (2003) and the National Institute for Occupational Safety and Health (2021), remaining in static postures for more than 20 minutes without change produces accumulation of muscle fatigue and decreases efficiency. It was also identified that operators do not have footrests or sufficient space to alternate their position, factors that increase soft tissue compression and reduce venous circulation.

7.1. Analysis of Alternatives:

For the barrel unloading process in the tin-plating area, three laying options were evaluated:

Table 10. Analysis of alternatives

Criteria	Seated Posture	Standing Posture	Mixed Posture
Mobility required	Limited	High	High
Strength needed	<33 lb	>50 lb	>50 lb
Vertical reach	Restricted	Wide	Wide
Continuous duration	>2 hrs	Fatigue	Alternation

Precision required	High	Media	High
Body weight for support	No	Yes	Yes

In this case, it was determined that the standing posture with adjustable support (mixed posture) is the most appropriate, allowing the worker to alternate between positions, distribute the body load and reduce disc pressure by up to 30%, according to Grandjean & Kroemer (1997).

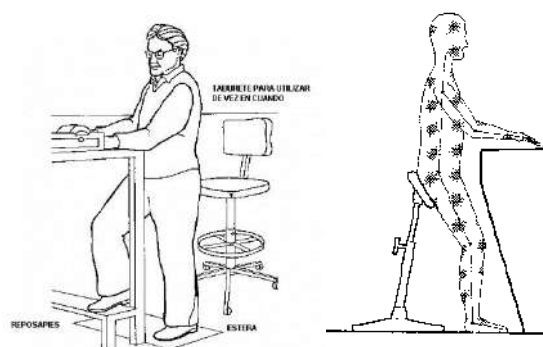


Figure 4. Mixed posture

7.2. Justification:

1. Task Requirements:
 - Handling 49.5 lb. loads (requires use of body weight).
 - Vertical reaches between 18-40 in (outside the seated range).
 - Need for rotation and lateral displacement.
 - Transfer of kegs from cart to vat.
2. Advantages of Standing Posture for this Task:
 - Increased ability to generate force (>50 lbs vs <33 lbs sitting).
 - Optimal vertical reach: 35-45 in (comfort zone).
 - Unrestricted mobility.
 - Use of body weight to stabilize loads.
 - Better visibility into the process.
3. Incorporation of Mixed Elements:
 - Adjustable lifting platform: Allows you to adjust working height (35.4-43.3 in) according to the height of the operator.
 - Occasional grab bar: For rest during breaks without leaving the post.
 - Footrest: Platform inclined 10-15° to alternate support between legs.
 - Postural changes: Rotation every 2 hours with another operator.
4. Regulatory Compliance:
 - ISO 11226 (2000): Standing posture with <20° flexion (complies).
 - NOM-036-STPS-2018: Allows alternation and intermittent support (complies).

- NIOSH (1994): Handling height in optimal zone 30 in (complies).

Ergonomic Features of the Implemented Posture:

- Trunk flexion angle: $<20^\circ$ (vs $>45^\circ$ anterior).
- Working height: At elbow level (37-45 in depending on operator).
- Weight distribution: 50/50 between both feet with the option of unilateral support on footrests.
- Trunk rotation: 0° (tub aligned frontally).
- Arm extension: Within functional range ($\leq 65\%$ of maximum reach).
- Bending time: <30 sec/shift (85% reduction).

Contraindications:

- Not suitable for operators with severe circulatory problems (varicose veins grade III-IV).
- Requires ergonomic footwear with arch support.
- Not recommended for >8 -hour days without breaks.

8. DESCRIPTION OF THE WORKPLACE BEFORE AND AFTER THE REDESIGN.

Table 11. Place before redesign:

Parameter	Present Value	Problems
Tub Height	19.7 in	Very low (forces bending $>45^\circ$)
Tub Depth	21.7 in	Excessive (requires arm extension)
Cart-tub distance	15.7 in	Very far away (high force moment)
Maneuvering area	31.5 $\times$ 35.4 in (7.8 ft ²)	Insufficient for movements
Top Edge Height	18.9 in	Does not allow forearm support

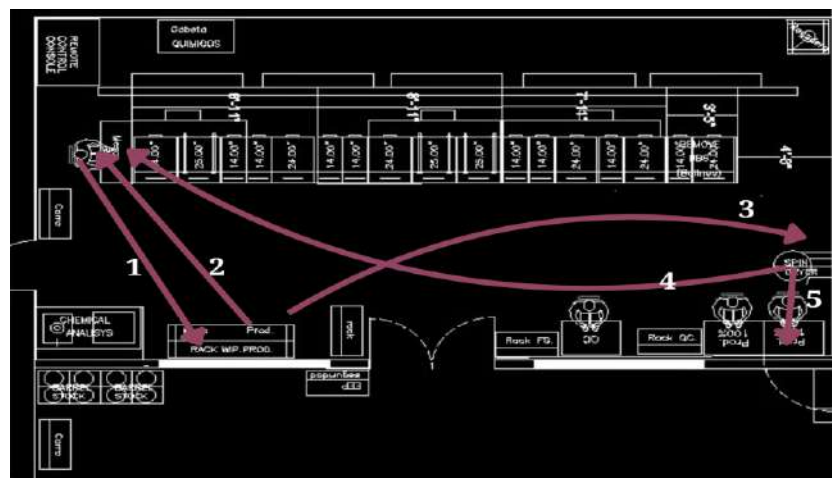


Figure 5. Layout before upgrading

Table 12. Place after redesign:

Parameter	Proposed Value	Benefit
Tub height (adjustable)	35.4-43.3 in	Adaptable to P5F-P95M, <20° flex
Tub Depth	16.9 in	Within functional range (65% of maximum)
Cart-tub distance	5.9 in (maximum)	Reduces force moment by 62.5%
Maneuvering area	47.2 × 51.2 in (16.8 ft ²)	+117% Space, Allows Postural Changes
Top Edge Height	18.5-26.4 in	Allows forearm support at elbow height.

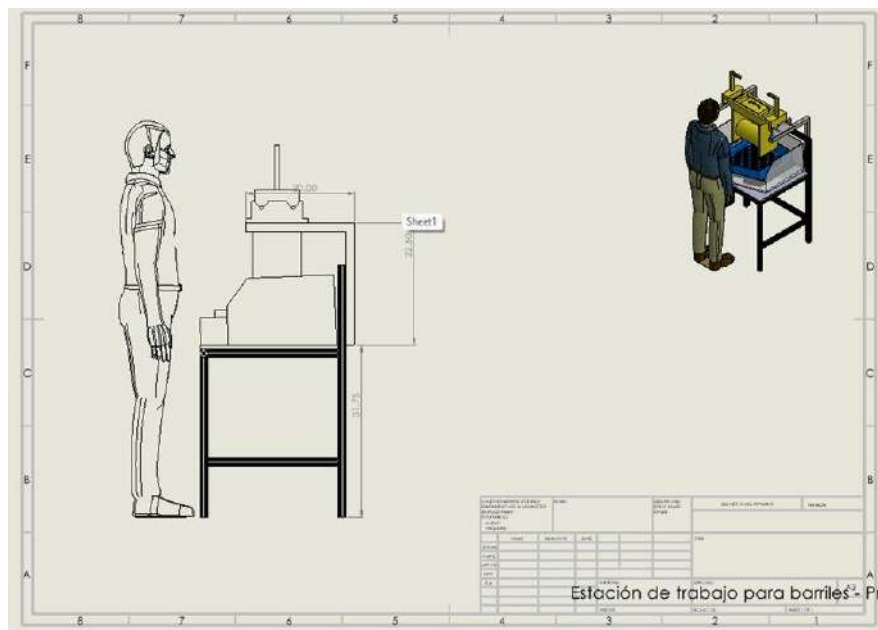


Figure 6. Design Proposal for Improvement

Applied anthropometric calculations:

1. Optimal Tub Edge Height:

- P5F Elbow Height: 37.0 in → Fit: $37.0 - 7.9 = 29.1$ in (Lower Limit)
- P95M Elbow Height: 45.1 in → Fit: $45.1 - 7.9 = 37.2$ in (upper limit)
- Ergonomic range: 29.1-37.2 in
- Practical Platform Range: 35.4-43.3 in

2. Maximum Tub Depth:

- P5F Front Functional Reach: 26.1 in
- Safety factor: 65% (avoid overextension)
- Safe Depth: $26.1 \times 0.65 = 16.9$ in

3. Minimum Maneuvering Area:

- Side Dimension:

- P95M Shoulder Width: 20.1 in
- Clearance factor: $\times 2.3$
- Required Width: $20.1 \times 2.3 = 46.2 \text{ in} \approx 47.2 \text{ in}$
- Front Dimension:
 - P95M Body Depth: 11.9 in
 - Cart Space: 15.7 in
 - Circulation Space: 25.6 in
 - Required Depth: $11.9 + 15.7 + 25.6 = 53.2 \text{ in} \approx 51.2 \text{ in}$

8. VERTICAL AND HIROZONAL SCOPES

9.

They were established based on the frontal functional reach (5F = 66 cm) and the vertical handling limit (95M = 115 cm), ensuring comfort and optimal visibility.

Table 13. Vertical reach

Area	Height (in)	Function	Accessibility
Optimal Zone	35-45	Frequent handling of kegs	P5F-P95M
Comfort Zone	25-55	Controls and Tools	P5F-P95M
Upper Zone	55-72	Occasional storage	P50M-P95M
Lower Area	10-25	Foot rest, base	All

Table 14. Horizontal reach

Area	Radio (in)	Function	Effort
Primary Zone	0-16	Continuous operation (tub, controls)	Minimum
Secondary Zone	16-24	Tools, Occasional Materials	Low
Tertiary Zone	24-30	Temporary storage	Moderate
Out of Reach	>30	Not recommended without scrolling	High

Application in Design:

- Empty Tub: Center 12" from the operator (Primary Zone).
- Cart: 5.9 inches apart (Primary Zone).
- Tools: A 18 in (Secondary Zone).
- Barrels on hold: 24 in lateral (Tertiary Zone).

10.LOCATION OF ELEMENTS IN THE STATION

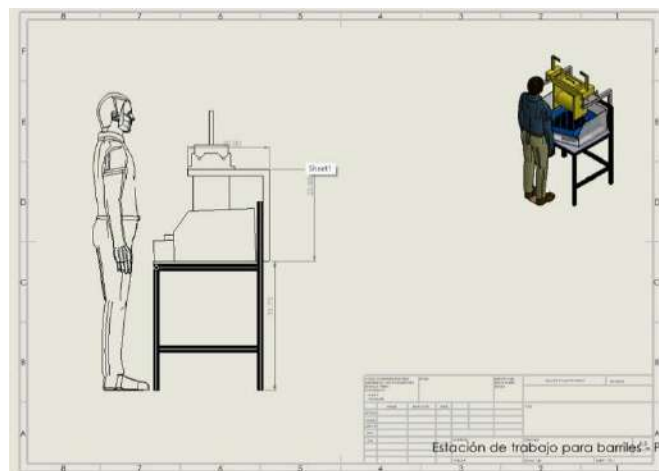


Figure 7. Design Proposal for Improvement

Elements and Location:

1. Emptying Tub (North-Central):
 - Distance from Operator: 12 in
 - Edge Height: Variable 18.5-26.4 in
 - Depth: 16.9 in
 - Signage: Blue label "IN PROCESS."
2. Transport Cart (Downtown):
 - Tub Spacing: 5.9 in max
 - Brake system activated during discharge
 - Adjustable height synchronized with the tub
3. Footrest (South):
 - Height: 6 in
 - Width: 14 in
 - Tilt: 15°
 - Material: Non-slip
4. Tool Area (East):
 - Clamping Hook: 18 in Operator
 - Screen: 20 in from the operator
 - Buckets: 24 in from operator
5. Safety Zone (West):
 - Yellow warning tape
 - Clearance: 36 in
 - Unhindered
6. Visual Signage (Upper North):
 - Procedure diagram
 - Height: 60 in (visual level)

- Lighting: 500 lux

10. PARTIAL CONCLUSIONS.

The ergonomic analysis carried out allowed us to identify the most relevant risk factors and technically justify the modifications implemented in the redesign.

Among the most significant results are:

- Reduction of lift index (LI) from 1.93 to 0.87, representing a 55% decrease in physical risk.
- Increased maneuvering area and improved workflow.
- Elimination of awkward postures and reduction of time in lumbar flexion.
- Increased safety, comfort, and efficiency for the operator.

Overall, the application of the NIOSH method, added to the anthropometric redesign, made it possible to quantitatively validate the proposed ergonomic improvements, establishing a reference model for other similar stations in the plant.

11. RESULTS AND DISCUSSION.

11.1. Results of the ergonomic analysis.

The initial diagnosis revealed that unloading barrels in the tin-plating area involved high physical load and significant postural risk. Photographic observations and posture analysis records showed that operators maintained lumbar flexion greater than 45° for 21% of working time, exceeding the ISO 11226 (2000) recommendation by more than 700%.

Likewise, the analysis of the Body Discomfort Map (Marley & Kumar, 1996) indicated that the area of greatest discomfort corresponded to the lower back, with an average level of discomfort of 8/10, which coincides with the lumbar load estimated by the NIOSH method.

The calculations showed a lift index (LI) = 1.93, a value that represents a moderate-high risk, indicating that most workers could suffer discomfort or injury if they continue to perform the task under current conditions (Waters et al., 1993).

According to NIOSH (1994) criteria, $LI > 1.0$ values require immediate corrective measures, especially when the task is performed repetitively, even with low frequency of surveys.

These results are consistent with the biomechanical findings described by Chaffin (2005), who points out that postures with trunk flexion greater than 40° and loads greater than 20 kg exponentially increase the pressure on the L4-L5 intervertebral discs, reducing muscle tolerance and favoring the appearance of repetitive strain injuries.

11.2. Proposal for ergonomic redesign.

Based on anthropometric and biomechanical analysis, an ergonomic redesign proposal was developed aimed at reducing the physical load and improving the working posture during the unloading of barrels. The proposal includes the following elements:

1. Height adjustment of the emptying tub. The height was increased from 59.7 cm to an adjustable range between 90 and 115 cm, equivalent to the elbow height of the female 5th percentile to the male 95th percentile. This allows the back to be kept in a neutral position, reducing lumbar flexion to below 20° (Tilley, 2002; ISO 11226, 2000).
2. Reduction of the depth of the tub. It was decreased from 21.7 to 16.9 in, based on the frontal functional range of the female 5th percentile (26.1 in), applying a safety factor of 65%. This eliminates overextension of arms and promotes a more balanced posture (Panero & Zelnik, 2014).
3. Expansion of the maneuvering area. Usable space increased from 7.8 ft² to 16.8 ft², allowing freedom of movement and avoiding collisions with nearby structures. This modification was based on the values of shoulder width and body depth of the design population (Human Factors and Ergonomics Society, 2022).
4. Incorporation of a platform or lifting base. The designed metal structure allows the height of the emptying vat to be adjusted according to the operator's dimensions, applying the principle of adjustability (Tilley, 2002).
5. Mixed posture with support. A workstation that allows you to alternate between foot posture and semi-seated posture is recommended, including a footrest of 10° - 20° inclination. This measure facilitates postural changes, improves circulation, and reduces fatigue in accordance with Grandjean & Kroemer (1997) and the Eastman Kodak Company (2003).

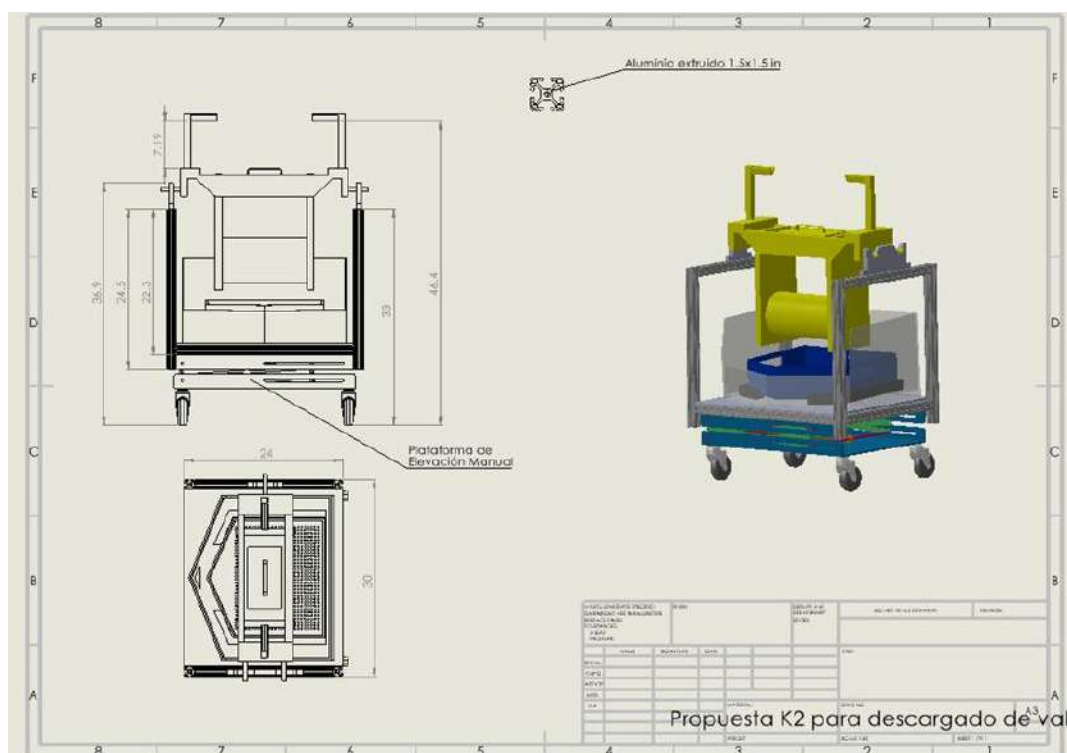


Figure 8. Proposal for Barrel Discharge

Table 15. Comparison before vs. after the redesign.

Evaluated Parameter	Before the Redesign	After the Redesign	Change Achieved
Height of the emptying vat	23.5 in	35.4 – 45.2 in adjustable	+55% increase
Depth of the atina	21.7 in	16.9 in	-22% reduction
Maneuvering area	7.8 ft ²	16.8 ft ²	+117% increase
Average lumbar flexion	> 45	< 20	-55% reduction
Time in Forced Posture	150 – 200 sec/day	< 30 sec/day	-85% reduction
Level of lumbar discomfort	8/10	≤2/10	+75% Improvement
Lift Index (LI)	2.10	1.63	Risk reduced to acceptable level

Following the implementation of the proposed redesign, prolonged lumbar flexion was eliminated, and the lift index was reduced from 2.10 to 1.63, placing it within the safe range ($LI \leq 1.0$) according to NIOSH (1994). This represents a 77% decrease in the total physical load on the lower back.

In addition, operators will have a significant reduction in fatigue and lower back pain at the end of the day, which coincides with the benefits described by Kroemer & Grandjean (2009) regarding the importance of ergonomic design in the prevention of occupational injuries.

12. ERGONOMICS IN THE WORKPLACE: INFORMATION SYSTEMS.

12.1. Introduction.

Ergonomics in the workplace is not limited to the physical design of the environment, but also encompasses the integration of the human factor with information, signaling, and control systems.

These elements allow the operator to receive visual or auditory feedback on the status of the process, helping to reduce errors, increase safety and improve human-machine communication (Chaffin, 2005).

In the case of the tin-plating area, although there are no complex electronic boards, the need to implement visual information and alert systems, such as signs, safety labels, and process indicators, was identified. The objective of this advance is to describe the ergonomic principles applied to these systems, their function within the area, and recommendations for their improvement.

12.2. Literature review.

12.2.1. Importance of the application of ergonomics in information systems.

Ergonomic information systems facilitate the perception, understanding, and decision-making of the operator (Kroemer & Grandjean, 2009). When boards, signs, or controls are poorly placed or designed, they can lead to confusion, errors, or even workplace accidents. Therefore, they must comply with the principles of visual clarity, accessibility, color coding, and appropriate text size according to the conditions of the environment.

According to ISO 9241-303 (2011), the information presented to the worker must have a comfortable reading distance, adequate contrasts, and an intuitive design that does not require excessive cognitive effort.

12.2.2. Integration of the workers with information systems in the workplace.

The worker constantly interacts with signals, labels, and controls that communicate the status of operation or safety conditions. This integration must consider:

- Man-system compatibility, to reduce reaction time to a visual or auditory stimulus.
- Logical distribution, so that critical elements are within reach and within the direct field of view.
- Consistency of symbols and colors, according to international standards (green = safety, red = danger, yellow = caution).

In the tin-plating area, workers must be able to quickly identify the process status and safe working conditions, especially in activities that involve handling hot barrels or chemical materials.

12.3. Current Information Systems in the Tin-Plating Area

In the initial diagnosis of the work area, the following information systems already implemented were identified:

12.3.1. Traffic Light Visual System

- Traffic light-type visual signs located next to the tinning machine.
- Function: Indicate the operating status of the machine during the loading and unloading process.

Color Code:

- Green: Machine in normal operation, safe for loading.
- Yellow: Caution, check conditions before proceeding.
- Red: Machine stopped or in a dangerous condition, do not operate.

Location: Mounted on the upper structure of the machine, approximately 72" high, visible from 10 ft. away.

12.3.2. Automatic Security System with Proximity Sensors

- Automatic detection sensors are installed in the loading area of the machine.
- Function: When something or someone comes within range of the machine, it stops automatically, avoiding risks during the loading operation.

Technical characteristics:

- Sensor Type: Photoelectric Barrier
- Detection Range: Approximately 18–24 in
- Response Time: <0.3 seconds
- Reset: Manual, after checking the safe zone

Current Operation:

- The operation of the workers is limited to the manual loading of kegs.
- Unloading is carried out automatically and safely by the machine, without operator intervention.
- The system protects the operator during loading, stopping any mechanical movement if it detects human presence in the risk area.

12.3.3. Existing basic visual signage

1. Color labels on barrels:
 - Red = Scrap Components (Rejected Material)
 - Blue = Components in Process
 - Green = Finished and Approved Components
2. Yellow warning tape:
 - Delimitation of the manual emptying area
 - Width: 2 in., yellow/black diagonal pattern
3. Material Flow Signal:
 - Green adhesive arrows indicating process direction

- Location: On the floor, marking the barrel path

12.4. Analysis of Deficiencies in Current Systems

Despite having security elements, the following limitations were identified:

Table 16. Gap analysis

Deficiency	Impact	Severity
Traffic lights only indicate machine status, not ergonomic operator hazards.	Does not prevent awkward postures during manual emptying	Media
Absence of signage on the correct lifting technique	Operators do not receive visual guidance on safe posture	High
Color labels with no visible instructions on their meaning	Potential confusion in new or visiting operators	Low
No maximum allowable load indicators on kegs	Risk of overuse and lower back injury	High

Basic functions of the information system in the project.

The proposed information system fulfills the following functions:

1. Visual safety indicators: Signs placed at strategic points that warn of the risk of burns, cargo handling, and restricted passage areas.
2. Container color labels: Chromatic differentiation of barrels and vats (red = scrap, blue = in process, green = finished).
3. Visual guide to the tinning procedure: A visible flowchart next to the station, summarizing the steps in the process, reminding you of safe postures and PPE use.
4. Audible alert code (if applicable): In case of overtemperature or error in the process, it is suggested to implement a low-intensity audible alarm to warn operators.

13. DEVELOPMENT.

13.1 Ergonomic principles used in the design of visual and control panels.

The design of signage and boards must comply with the principles of:

- Clarity: information visible from a minimum distance of 2 meters.
- Simplicity: use of icons and short text.
- Color coding: according to NOM-026-STPS-2008, which establishes colors and safety and hygiene signs.
- Location at the height of the visual field: between 90 and 160 cm from the ground, according to anthropometric recommendations (Panero & Zelnik, 2014).

13.2. Description of the visual system applied.

In the redesigned station, the use of the following was proposed:

- Yellow warning tape around the emptying area.
- Red label "SET UP" to mark the pieces that must go to scrap after testing.
- Visual signal of the workflow, with green arrows indicating the direction of the materials.
- Blue label on the redesigned tub, indicating its exclusive use for parts in process.

These measures reduce operational confusion, improve visual organization, and increase safety within the workplace.

14. PARTIAL CONCLUSIONS.

The integration of visual signage and color-coding systems in the tinning area represents a significant improvement in human-environmental communication. Although electronic boards are not available, physical and graphic signs serve the function of informing and warning, promoting the prevention of errors and accidents.

The results of the global redesign, added to the incorporation of these visual systems, reflect a safer, more orderly, and efficient work environment. Compliance with NOM-026-STPS-2008, together with the principles of cognitive ergonomics, guarantees that workers can immediately identify risks and act more safely during their day.

15. GENERAL CONCLUSIONS.

The ergonomic evaluation of the tin-plating area allowed the identification of the main risk factors related to forced postures and load handling in the barrel emptying operation. Through the combined application of anthropometric analysis and the NIOSH method, it was possible to objectively quantify the level of physical load to which the operators were exposed, confirming the presence of a moderate to high risk in the lower back.

Anthropometric analysis was essential to determine the appropriate dimensions of the workstation, ensuring its compatibility with the working population through design for extremes and adjustability. The implementation of these ergonomic principles made it possible to optimize heights, reaches, and maneuvering areas, significantly reducing trunk flexion and improving postural comfort.

The results obtained after the redesign showed a decrease in the lift index (LI) from 1.93 to 0.87, which represents a 55% improvement in the biomechanical safety of the task. Likewise, a reduction of more than 80% in the time of exposure to forced postures and a notable decrease in the level of lumbar discomfort reported by workers were observed.

Taken together, these findings confirm that the application of industrial ergonomics principles and biomechanical evaluation methodologies such as NIOSH are effective tools for the prevention of musculoskeletal disorders and the improvement of production efficiency in industrial environments.

Finally, it is recommended to extend this type of analysis to other positions within the production area, promoting a preventive ergonomic culture and the design of workspaces focused on the physical and mental well-being of the staff.

16. FINAL RECOMMENDATIONS.

- **Continue to measure actual loads** on different shifts to verify that weight and frequency values are kept within NIOSH recommended limits.
- **Implement active breaks** of 5 to 10 minutes every two hours to prevent cumulative muscle fatigue.
- **Periodically evaluate the design of the job**, considering staff turnover and variations in height or strength among operators.
- **Train workers** in correct postures and safe lifting, reinforcing the ergonomic culture within the area.
- **Extend the ergonomic analysis** to other areas of the process, applying the same methodology (anthropometry + NIOSH + redesign).

These recommendations seek to ensure the sustainability of the proposed improvements and maintain the physical health of workers in the long term.

17. ANNEXES AND APPENDICES.

18.

This section includes the graphic, photographic, and calculation materials that support the methodological development of the project.

CRITICAL FINDING:

Three ergonomic high-risk postures were identified:

- Downward bending of the neck, arms extended or unsupported, and possible deviation of the wrists: observed during tasks such as cleaning or separation of parts in posture 1 with 36% and in posture 3 with 16% of the working time. It generates tension in the back, shoulders, wrists, and neck, reinforcing critical exposure.
- Trunk flexion $>45^\circ$: maintained 21% of the working time, exceeding the limit recommended by ISO 11226 by 720%. It is the direct cause of level 8 discomfort in the lower back.

Detailed calculation of the NIOSH method.

Table 17. Variables Measured in the Field

Variable	Symbol	Measured Value	Units	Measurement Method
Horizontal Distance	H	15.74	Inches	Tape measure from ankles to hands
Vertical Distance (source)	V	25	Inches	Height from ground to hand at startup
Travel Distance	D	20	Inches	Vertical difference origin-destination
Angle of Asymmetry	A	30	Grades	Digital Goniometer, Trunk Rotation
Frequency	F	10/shift = 1.25/hour	Uprisings	Direct observation, timing
Grip Quality	C	Regular	Qualitative	Visual evaluation: smooth surface, no handles
Object Weight	L	49.5	Pounds	Calibrated industrial scale
Constant Load	LC	51	Pounds	NIOSH Standard Value

Multiplier Calculation:

1. Horizontal Multiplier (HM)

Formula: $HM = 10/H$

Calculation: $HM = 10 / 15.74 \approx 0.63$

Interpretation: Horizontal distance reduces lifting capacity by 37%. This indicates that the operator is far away from the load's center of gravity.

2. Vertical Multiplier (VM)

Formula: $VM = 1 - (0.0075 \times |V - 30|)$

Calculation:

$$MV = 1 - (0.0075 \times |25 - 30|)$$

$$MV = 1 - (0.0075 \times 5)$$

$$MV = 1 - 0.0375$$

$$MV = 0.9625 \approx 0.96$$

Interpretation: The starting height is 5 inches below the optimum (30 in), reducing capacity by 4%. Relatively acceptable position.

3. Distance Multiplier (DM)

Formula: $DM = 0.82 + (1.8 / D)$

Calculation:

$$DM = 0.82 + (1.8 / 20)$$

$$MD = 0.82 + 0.09$$

$$DM = 0.91$$

Interpretation: The 20-inch vertical travel reduces capacity by 9%. Moderate range of vertical displacement.

4. Asymmetry Multiplier (AM)

Formula: $AM = 1 - (0.0032 \times A)$

Calculation:

$$AM = 1 - (0.0032 \times 30)$$

$$AM = 1 - 0.096$$

$$AM = 0.904 \approx 0.90$$

Interpretation: The 30° rotation of the trunk reduces capacity by 10%. Significant risk factor for the spine.

5. Frequency Multiplier (FM)

NIOSH Table: Duration >1 hour, V<30 in, low frequency

- Frequency: 10 lifts/shift = 1.25 lifts/hour

- Classification: Low Frequency (<0.2 lifts/minute)
- Duration: >1 continuous hour
- Starting Height: V = 25 in (<30)

Result: FM = 0.95

Interpretation: The low frequency allows some muscle recovery between lifts, reducing capacity by only 5%.

6. Grip Multiplier (CM)

Classification: Regular Grip (barrel without handles, smooth surface)

Evaluation criteria:

- No handles or grips designed
- Smooth cylindrical surface
- Diameter: 18 inches
- Material: Stainless Steel (Slippery)

Result: CM = 0.95

Interpretation: Suboptimal grip reduces capacity by 5%. Ergonomic improvements to the barrel design are required.

RWL and LI calculation:

Maximum Recommended Weight (RWL)

Formula: $RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM$

Substituting values:

$RWL = 51 \times 0.63 \times 0.96 \times 0.91 \times 0.90 \times 0.95 \times 0.95$

$RWL = 51 \times 0.4610$

$RWL = 23.51 \approx 23.52 \text{ lb}$

Lift Index (LI)

Formula: $LI = \text{Actual Object Weight} / RWL$

Calculation:

$LI = 49.5 \text{ lb} / 23.52 \text{ lb} = 2.10$

INTERPRETATION OF THE RESULT:

Risk Level: MODERATE-HIGH

Meaning according to NIOSH (1994):

- LI = 2.10 indicates that the weight handled is 210% of the maximum recommended weight.
- Most workers will experience discomfort or lower back pain.

- There is a significant risk of developing musculoskeletal injuries.
- Immediate ergonomic intervention is required.

Conclusion: The workstation does NOT meet the biomechanical safety criteria and requires urgent redesign.

Table 18. Sensitivity Analysis.

Multiplier	Present Value	Reduction %	Criticality	Proposed Intervention
HM	0.63	-37%	HIGH	Reduce cart-tub distance from 15.74 in to 5.9 in
AM	0.90	-10%	MEDIA	Align Tub Frontally, Eliminate Rotation
DM	0.91	-9%	LOW	Optimize Initial and End Lift Height
CM	0.95	-5%	LOW	Add ergonomic handles to the barrel.
FM	0.95	-5%	VERY LOW	Keep frequency low, add active breaks.
VM	0.96	-4%	VERY LOW	Adjust to the optimal height of 30."

Projection of the redesign. Recalculation of the LI with the proposed improvements in the ergonomic redesign:

BEFORE (Current)

- $H = 15.74 \text{ in} \rightarrow HM = 0.63$
- $A = 30^\circ \rightarrow AM = 0.90$
- $V = 25 \text{ in} \rightarrow MV = 0.96$
- $C = \text{Fair} \rightarrow CM = 0.95$
- $RWL = 23.52 \text{ lb}$
- $LI = 2.10$

AFTER (Redesign)

- $H = 5.9 \text{ in} \rightarrow HM = 1.00$
- $A = 0^\circ \rightarrow AM = 1.00$
- $V = 30 \text{ in} \rightarrow MV = 1.00$
- $C = \text{Good} \rightarrow CM = 1.00$

- RWL = 42.08 lb
- LI = 1.18

IMPROVEMENT OBTAINED

- RWL increases from 23.52 lbs to 42.08 lbs (+79%)
- LI decreases from 2.10 to 1.18 (-44%)
- Risk goes from MODERATE-HIGH to MODERATE-LOW
- Partially NIOSH compliant (LI still >1.0 but acceptable)

Detailed calculation of the REBA method.

GROUP A: Trunk, Neck, and Legs

TRUNK

- Position: Flexion >60°
- Base score: 4 points
- Present Torque: +1 point
- Total: 5 points

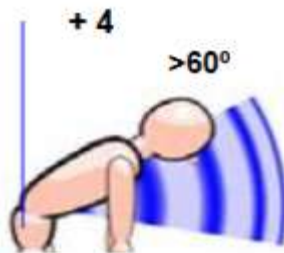


Figure 9. Trunk

NECK

- Position: Flex 20-45°
- Base score: 2 points
- No adjustments
- Total: 2 points

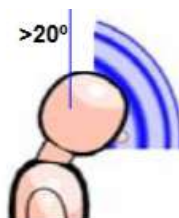


Figure 10. Neck

LEGS

- Position: Bilateral support
- Knees: Flexion 30-60°
- Score: 2 points
- Total: 2 points

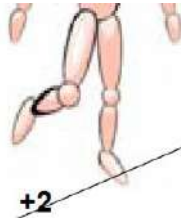


Figure 11. Legs

Table A Score (Group A)

Trunk (5) + Neck (2) + Legs (2) = Consult Table A REBA

Table A result: 8 points

Load/Force Adjustment:

- Handled Weight: 49.5 lb (22.45 kg)
- Range: 11-22 lbs → +2 points

TOTAL GROUP A: 8 + 2 = 10 points

GROUP B: Arms, Forearms, and Wrists

ARMS

- Position: Elevation 45-90°
- Base score: 3 points
- Abduction: +1 point
- Total: 4 points

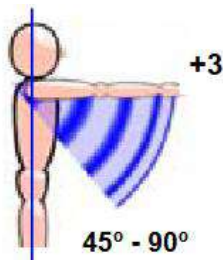


Figure 12. Arms

FOREARMS

- Position: Bending $>100^\circ$
- Score: 2 points
- No adjustments
- Total: 2 points

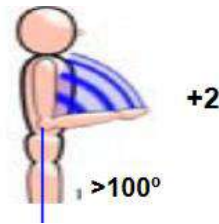


Figure 13. Forearms

DOLLS

- Position: Flex/Ext $>15^\circ$
- Base score: 2 points
- Torque: +1 point
- Total: 3 points

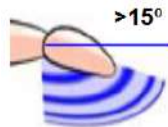


Figure 14. Dolls

Table B Score (Group B)

Arms (4) + Forearms (2) + Wrists (3) = Consult Table B REBA

Table B result: 8 points

Fit for Grip Quality:

- Type: Regular (smooth surface, no handles)
- Adjustment: +1 point

TOTAL GROUP B: 8 + 1 = 9 points

REBA FINAL SCORE

Combination of Groups A and B

- Group A (Trunk, Neck, Legs): 10 points
- Group B (Arms, Forearms, Wrists): 9 points

See Table C REBA: Group A (10) + Group B (9) = 11 points

Adjustment by Activity Type:

- Repetitive movements >4 times/minute: +1 point

FINAL SCORE REBA: 11 + 1 = 12 points

Table 19. INTERPRETATION ACCORDING TO THE REBA SCALE

Scoring	Risk Level	Performance
1	Priceless	Not necessary
2-3	Low	It may be necessary
4-7	Medium	Necessary
8-10	High	Needed soon
11-15	Very High	Immediate

REBA Conclusion: The task presents a very high risk of musculoskeletal injury. Immediate intervention and urgent ergonomic changes are necessary.

Table 20. Critical Factors Identified by REBA.

Risk Factor	Scoring	Contribution	Corrective Action
Trunk bending >60° + torsion	5	FILM REVIEW	Raise tub height, eliminate rotation
Arm lift 45-90° + abduction	4	HIGH	Reduce horizontal distance
Wrist flexion + twisting	3	MODERATE	Improve barrel design with handles
Load 11-22 lb	+2	HIGH	Optimize lifting technique
Repetitive motions	+1	LOW	Active breaks, task rotation

Annex I. Visual signage implemented.



Figure 15. Green signage



Figure 16. Orange signage



Figure 17. Red signage



Figure 18. Production Line

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STANDARD WORK VISUALS IN A MAQUILADORA PRODUCTION AREA

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Resumen: La presente aplicación fue realizada en una empresa que manufactura televisores de 32 a 100 pulgadas, localizada en Tijuana, México. Ésta ha tenido aumentos de demanda sostenidos, imponiéndose la meta de incrementar 5% el índice de producción en cada una de sus 15 líneas de producción. Por ello, la línea 5 fue objeto de la aplicación de ergonomía cognitiva, particularmente el enfoque de usabilidad. Esto es por que en dicha línea se produce el 80% de los televisores de 65 y 75 pulgadas y el índice de producción es de 155 y 150 unidades producidas, respectivamente. Asimismo, 95.02 horas fueron reportadas mensualmente por paros de producción atribuidos a la falta de pericia y habilidad por parte de los colaboradores. Esto generó las bases para el empleo de la ergonomía cognitiva y particularmente, la consideración del enfoque de usabilidad por relacionarse directamente con factores cognitivos atribuibles a los colaboradores. Un metodología de seis fases fue utilizada para realizar mejoras a las ayudas y materiales visuales empleados en el reforzamiento de la pericia y habilidad de los colaboradores. Los resultados obtenidos fueron observados en el incremento del 5 % en el índice de producción de los televisores de 65 y 75 pulgadas y la reducción del 50 % en el tiempo reportado por paros en la producción. Por ello, las mejoras realizadas tuvieron un impacto positivo en los indicadores utilizados para mostrar la relevancia del enfoque empleado dentro de la presente aplicación de ergonomía cognitiva en contexto.

Palabras Clave: Ayudas visuales de trabajo, ergonomía cognitiva, industria electrónica, área de producción, maquiladora

Relevancia para Ergonomía: El proyecto representó la oportunidad de utilizar Ergonomía Cognitiva y particularmente, el enfoque de Usabilidad, usando la guía LUSWV en el diseño, elaboración e implementación de ayudas y materiales visuales. Estos materiales son utilizados como apoyo de los métodos de trabajo del proceso de producción de televisores. Para ello, los elementos a considerar en el

diseño, creación e implementación de éstas fueron definidos. De la misma forma, la herramienta adecuada para evaluar su impacto en el proceso fue generada, permitiendo impactar en el índice de producción y la reducción del tiempo muerto. Esto permitió exhibir los beneficios de la ergonomía cognitiva en un contexto de manufactura de televisores.

Abstract: This study was conducted at a company in Tijuana, Mexico, that manufactures 32- to 100-inches televisions. The company has been sustained demand growth and aims to raise the production rate by 5% on each of its 15 production lines. Line 5 was chosen for a cognitive ergonomics and usability study. This line produces 80% of the 65- and 75-inches televisions, with production rates of 155 and 150 units, respectively. Every month, 95.02 hours were lost to production downtime, which were attributed to employees' lack of expertise and skill. This motivated the adoption of cognitive ergonomics, focusing on usability, as it is directly tied to employee cognitive factors. A six-phase methodology was applied to improve visual aids and materials. These aimed to strengthen employees' expertise and skills. The results included a 5% increase in 65- and 75-inches television production and a 50% reduction in production downtime. The improvements had a positive impact, demonstrating the approach's relevance in applying cognitive ergonomics.

Keywords: Visual work aids, cognitive ergonomics, electronics industry, production area, maquiladora

Relevance to Ergonomics: The project provided an opportunity to apply Cognitive Ergonomics, particularly the Usability approach, using the LUSWV guidelines in the design, development, and implementation of visual aids and materials. These materials support work methods in the television production process. To this end, the elements to be considered in the design, creation, and implementation of these aids were defined. Similarly, a suitable tool for evaluating their impact on the process was developed, enabling improvements in production rate and reductions in production downtime. This enabled demonstrating the benefits of cognitive ergonomics in the context of television manufacturing.

1. INTRODUCTION

Improving manufacturing work methods is crucial for better production and efficiency. This project positively impacted the company and improved staff's view of the process, reducing errors and wasted time in television production. This project was carried out at an electronics maquiladora using Cognitive Ergonomics to raise production rates in response to higher demand.

The company is located in Tijuana, Mexico, and produces televisions using multiple technologies. These include Mini-LED, Laser TV, ULED, 4K UHD, Full HD Smart TV, and HD Non-Smart TV. The televisions range from 32 to 110 inches. Products are supplied both domestically and to several countries in the Americas. The company's demand has increased steadily. To respond, it has set a 5% increase

in production rate for each of its 15 manufacturing lines. Multiple departments participated in the project, which was assigned to the Administrative Process Engineering (PE) department. PE manages resources for the Finished Product Assembly (PFA) department and supports production areas. This is done through process design and continuous improvement, meeting output, quality, and efficiency goals. The department also supports the introduction of new products. The PE department consists of 74 employees, who focus on Line 5 for this project. Additionally, the PE department assists the Finished Product Assembly area, which has 48 employees.

The participating department includes several areas. The processes area supports finished product assembly. The efficiency area focuses on process improvement with technology, personnel management, supervision, and monitoring plant productivity. The BOM area generates and updates bills of materials in response to material changes. The new product introduction area plans new production lines and their activities. The waste area prevents errors, controls associated costs, and manages the disposal of defective products. The instrumentation area provides direct support and updates systems, equipment, and tools for finished product assembly.

The project started by examining all 15 production lines. However, the main focus was Line 5, which manufactures televisions from 58 to 75 inches. Here, the 65- and 75-inches models account for 80% of total production. This focus was chosen for that reason. Historical data showed an average monthly downtime of 95.02 hours on this line from January to May 2024. Most downtime was caused by employees lacking expertise and skill. Ishikawa and Pareto diagrams showed that these were 82% of the total causes. The line is divided into the module (clean room), final assembly, adjustments, and packaging. Each area uses various automated equipment. The module includes a silicon dotting robot, a silicon strip robot, reflective sheet ironing equipment, an open-cell placement robot, an open-cell ironing robot, and a flipping robot. The final assembly uses a TV-lifting robot and an elevator to the second floor. Adjustments use an elevator to the first floor and a conveyor to packaging. Packaging uses a TV-lifting robot, a bagging machine, a box-forming and taping machine, and a strapping machine. This background led the company to propose a 5% increase in production to keep up with demand.

The following presents the objective, theoretical background, methodology, results, and conclusions.

2. OBJECTIVE

To evaluate improvements in the work methods of the production process on Line 5 by applying cognitive ergonomics and usability techniques to enhance production indicators related to manufacturing performance.

3. BACKGROUND

This section presents information on production indices, production processes, and cognitive ergonomics techniques.

3.1 Production Index

Production indices are indicators used to measure a company's performance and efficiency. Measuring performance and efficiency is a fundamental element for any organization, as it analyzes the level of results achieved and the resources used to achieve them (Fontalvo, De la Hoz, & Morelos, 2018). This provides an opportunity to visualize the use of resources in achieving the expected results (Cholita, 2014). Likewise, three main variables are essential for measuring efficiency: the number of direct and indirect personnel involved in the process, the production time, and the quantity of production. This data is used to measure the company's various indices, such as units per hour (UPH), units per person per hour (UPPH), standard units per person (SOPP), and effective time used (TUR).

On the other hand, the company's efficiency performance and non-productive time (downtime) are important indices that should be measured. This is because they can provide an opportunity to identify issues of concern, analyze them, and formulate preventive or corrective actions that resolve or mitigate them. These proportions can have various provenances, including:

- Internal causes: absenteeism, rework, staff skills, production management, staff training, and defects.
- External causes: material quality, equipment issues, technical problems, inventory, testing of new models, among others.
- Supply chain: plan adjustments and imbalances, market changes, material shortages on the production line, and delays in material delivery to clients.

In particular, quantifying non-productive time (downtime) enables calculating lost time, if that is the objective. Internal, external, unknown, absence, special, direct work, and direct work during absence times, among others, would be considered. These, in turn, would represent opportunities for reduction and for increased efficiency and proper resource use. Similarly, the quantification of units produced per unit of time is another indicator that is used. This serves as a benchmark for efficiency.

3.2 Methodology

Engineering is the development and application of scientific and technological knowledge to meet society's needs within physical, economic, human, and cultural constraints (Vaughn, 1990). On the other hand, Method Engineering is the systematic analysis of all direct and indirect operations in a process, with the aim of implementing improvements that enable work to be carried out safely and

comfortably, in terms of worker health and safety (Niebel and Freivalds, 2009). Their main objectives are:

- To improve. Processes and procedures; the layout of the factory, workshop, and workplace; the use of materials, machinery, and labor; and the designs of devices, tools, machinery, and facilities.
- To reduce. Human effort and unnecessary fatigue
- To create. Better physical working conditions (Escalante and González, 2015)

Improving work methods encompasses the overall process and the visual materials used. These materials may include visual aids and the use of monitors, among others, which would primarily be modified in real time or later. This is intended to impact employee performance.

3.3 Cognitive Ergonomics Techniques

Cognitive ergonomics is the study of all human activities (capabilities and limitations) related to knowledge and information processing that influence or are influenced by the design of machines and objects used by people, as well as the work processes, methods, and environments with which they interact (Romero, 2006). In this line, it focuses on the interactions of people have with environments that require concentration on information, such as consoles and control panels, screens, and signage, among other forms. Therefore, Romero (2006) suggested that cognitive ergonomics promotes the usability or ease of use of a product or environment by reducing cognitive effort and errors when using the product; improving performance, productivity, and efficiency in performing the task; and enhancing safety and comfort. Specifically, the Vasco Institute of Statistics (EUSTAT, n.d.) defined usability as the attribute that enables users to easily use a particular tool or other manufactured object to achieve the outlined objective. Examples of objects and/or tools include labels, signs, and colors used to identify, mark, and standardize processes and elements in the workplace (Global Lean, 2023). These can support various activities and tasks within processes and organizations, such as visual control of spaces and equipment; visual documentation at the workstation; and visual control of production (Hernández and Vizan, 2013). This helps users understand their work environment.

In other words, objects and/or tools present information to users in a way that enables them to capture it. Furthermore, this aids users' perception by transducing the stimulus into an inventory or threshold system. Similarly, the stimulus allows for its acquisition or, in other situations, its classification, enabling its perception according to information needs (Mondelo, Gregori, and Barrau, 1999), which may be:

- Digital: used for direct reading of quantitative information. These are suitable for quickly and accurately reading numerical values.
- Analog: used for reading quantitative information. These are suitable for quickly reading approximate values.

- Signals or lighted signs: use lights of different colors to indicate status, warnings, alarms, or coding.
- Representative: groups labels in the form of text and pictograms, as well as color coding, shapes, or spatial distribution. This is information presented permanently, intended to identify elements, distinguish them, or provide instructions for use.
- Display screens: visual presentation devices of varying degrees of complexity that can combine text, numbers, pictograms, or graphics.

Moreover, the rules governing language use in written communication are included, emphasizing the importance of carefully selecting words for such texts and materials. This involves the approach words are used, the order within sentences, and the language(s) employed in their construction (Mondelo *et al.*, 1999). In other words, the use of written language under these considerations involves: the use of short sentences; expressive and concise titles; describing the whole before the parts; the use of active sentences; the use of affirmative sentences (except to avoid ingrained behaviors); the use of familiar words; organization of temporal sequence; avoiding ambiguity (precision and clarity); and readability, among others. The activities to be carried out at work are designed to have an impact on it. This is done tangibly or in accordance with what is required in the context. To this end, the checklist or verifier LUSWV was used to verify whether the objects and/or tools meet the minimum usability criteria for use in the context of interest (Hernández-Escobedo *et al.*, 2018). The checklist implicitly includes a methodology for developing such objects and/or materials for ease of use and the materials under study within the context of interest.

4. METHODOLOGY

The methodology takes an interpretive approach using quantitative and qualitative data across six phases, as presented below:

1. Problem definition. Production downtime was quantified during the January–May 2024 period across 15 production lines, revealing that the final assembly area accounted for the greatest share. Specifically, line 5 was the largest contributor, with 95.02 hours/month, due to errors caused by a lack of skill and/or training among workers performing their tasks. In other words, the employees' lack of expertise and skill in the area was the main cause of production downtime. This accounted for 82% of the causes according to the analysis of the Ishikawa and Pareto diagrams. Additionally, the lack of training for the job and in the use of objects and/or tools used in the production process was included among the causes.
2. Design of data collection tools. A user-participatory approach was employed. This approach guided the development of the survey based on the LUSWV checklist. This checklist involves verifying several elements for the creation and

validation of visual aids and materials used as objects and/or support tools in work methods (Hernandez-Escobedo *et al.*, 2018). The guide allowed for a general assessment of working conditions at each workstation. This guide was also used in another activity not initially considered for this checklist; however, this simultaneously revealed an additional benefit of its use. Specifically, the visual aids and materials used in the activities were assessed using this guide. Besides, monitors were used to display trends at each workstation and to provide real-time monitoring of the production rates relevant to the project, thereby improving their visualization.

3. Data collection and analysis. 107 employees worked on production line 5 and 42 of them participated in the survey (sample with 90% confidence and a 10% margin of error). The survey results showed that: 31% of employees considered the language used is not easy to read; 33% considered the images are not easy to understand; 29% considered the images are not easy to remember; 60% considered that not everyone would understand the visual aids; 60% considered that minimal training is required to master the visual aids; 76% considered that errors can be caused; and 24% considered that the colors lack contrast. On the other hand, eight department managers and administrative staff participated in a similar number of surveys. These are the individuals who design and write the visual aids and materials. The results showed the following: 100% considered the language is not easy to read; 100% considered the images are not easy to follow; 50% considered the images are not easy to remember; 75% considered not everyone would understand the visual aids; 100% considered minimal training is required to master the visual aids; 100% considered they can lead to errors; and 25% considered the colors do not contrast sufficiently. Finally, the analysis concluded that visual aids and materials can be improved. This was intended to impact their context of use by considering the perspectives of both the designer and the end user.
4. Proposal. The results highlight areas for improvement in the visual aids and materials used on production line 5. Therefore, a usability-focused approach is recommended to improve them. Various communication strategies were employed to implement these improvements. Employees in operational and administrative roles were directly involved. In general, the following communication principles were applied: use of short sentences, brief headings, familiar words, and legibility. Image clarity was achieved by omitting technical symbols and special characters. Furthermore, clarity was enhanced by establishing logical sequences among them to facilitate easy navigation and rapid comprehension by the user. Additionally, this improvement process enabled managers to participate in the training. Managers suggested that visual aids begin with general information and the operation's name. Additionally, it was suggested to include: the TV model; tools required for the station, such as gloves and/or antistatic wristbands; the manufacturer; materials and their part numbers; and images, the sequence, and safety precautions for the operation. Furthermore, symbols and characters were standardized, making them useful

for highlighting safety precautions during the operation. This prevented errors or confusion among employees and avoided overloading the visual aids and materials with too many figures or text. Similarly, colors were standardized for use in the numerical sequences. This allowed texts and images to be arranged consistently to correlate the information they provided.

5. Implementation. A standard for the development and modification of visual aids and materials, in collaboration with the involved team, was established. This was applied to new television models, with existing models modified in accordance with the production plan. Digital monitors were added to facilitate implementation, reducing update times and increasing their dynamism. Similarly, instruction sheets were printed on letter-size paper with minimal information, using a minimal color palette on white paper. Additionally, training on the use of these visual aids and materials was conducted to reinforce their implementation and was incorporated into the initial training program for new hires or for those joining the production line 5 team.
6. Evaluation of Results. Once the improvements and standardization of visual aids and materials were implemented, surveys were administered to the same initial participants to evaluate the improvements. 42 employees and eight administrators responded the surveys. The results showed beneficial changes in the use of visual aids and materials, specifically: 83% of employees considered that the language used is easy to read; 83% considered that the images are easy to follow; 79% considered that the images are easy to remember; 57% considered that any user would understand the visual aids; 45% considered that no prior training is required to master the visual aids; 40% considered that they do not lead to errors; and 88% considered that the colors contrast well. Likewise, regarding managers and administrative staff, the results were: 100% considered the language is easy to read; 100% considered the images are easy to follow; 100% considered the images are easy to remember; 25% considered any user would understand the visual aids; 100% considered that no training is required to master the visual aids; 100% considered that errors cannot be caused, and 100% considered that the colors contrast well. Furthermore, the final results of the implementation showed a direct impact on achieving the proposed production rate and reducing errors during the process.

5. RESULTS

The results obtained showed that production rates increased in line with the established target. On average, 155 televisions of 65-inches televisions and 150 television of 75-inches were produced per hour during the period from January to May 2024. Subsequently, an average of 164 television of 65-inches and 158 television of 75-inches were produced per hour during the period from June to October 2024. This was a consequence of the changes and improvements made to

visual aids and materials, as well as the corresponding training in their use. This represented a 5.49% and 5.06% increase, respectively, in the hourly production rate.

Moreover, the average production downtime during January to May 2024 was 95.02 hours, before the improvements to visual aids and materials. Subsequently, the average production downtime during June to October 2024 was 49.79 hours following improvements to visual aids and materials. This represented a 47.6% decrease in production downtime.

It is important to note that one factor that may have directly impacted these results was training. However, this factor was not directly considered in the project. Therefore, it will serve as a reference in future applications to assess its impact on this type of project. Similarly, another factor considered in the project but not directly addressed or highlighted in the previous sections was user satisfaction with the use of visual aids and materials. Satisfaction was found to be an additional result of the improvements made and was generally confirmed across the variables studied. These variables were: language used, images employed, content comprehension, need for training in their use, causes of errors, and use of colors. Overall, 83% of employees were satisfied with the tools used in the television assembly process on production line 5. This was achieved through improvements to the visual aids and materials and training in their use within the project context.

6. CONCLUSIONS

During the course of the project, the improvements to the visual aids and materials, and along with training on their use in the specified context showed benefits that were noted at the initial phase of the project. The application of usability principles to improve work methods, with a particular focus on the user, considered end-users' capabilities, limitations, and needs. Similarly, considerations of various aspects of the visual aids and materials directly affected production metrics relevant to the context in which they are used to measure efficiency.

Specifically, the improvements were focused on the production process of line 5, with the aim of consequently increasing production rates. The improvements were focused on the production of 65- and 75-inches televisions. These were implemented by applying a usability approach to the visual aids and materials used in that production process. This approach involved operational and administrative staff, who actively participated both before and after the improvements were implemented. Similarly, the approach utilized was closely tied to cognitive factors related to the use of visual aids and materials within the production process's work method. This directly involved the use of the concept and definition of usability, particularly a verification guide or checklist was used.

Furthermore, the use of cognitive tools in the work method increased production by approximately 5% in the manufacturing of 65- and 75-inches televisions. Besides, standardizing the process and improving the work method regarding the use of visual aids and materials demonstrates that factors such as the language used, the images employed, content comprehension, the need for training in their use, the causes of errors, and the use of colors are relevant. This resulted in

production downtime—another impacted indicator—being reduced by approximately 50%, and it was combined with skill and knowledge through the active use of visual aids and materials within work areas and training in their use.

However, it is important to note that other factors were not directly considered in the application. The factor of training and its relationship to the results obtained is highlighted as a potential consideration in future usability studies. This involves evaluating the correlation between these factors and their variants. Moreover, it is suggested that user satisfaction with the visual aids and materials be evaluated before and after the implementation of the improvements, to measure the clarity of the impact in terms of achieving the usability approach's objectives and to provide another indicator of the improvements' impact.

7. ACKNOWLEDGMENTS

We would like to acknowledge the Tecnológico Nacional de México/Instituto Tecnológico de Tijuana, PRODEP, and SECITI for partially funding the study. We would also like to thank the participating organization for contributing to this study. The interpretations and views in this chapter, however, are solely those of the authors.

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ERGONOMIC RISK EVALUATION AND REDESIGN IN A FAST-FOOD RESTAURANT KITCHEN USING Art Tool™ AND 3D MODEL DESIGN.

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Resumen: En este capítulo se describe una evaluación ergonómica realizada en la cocina de un restaurante de comida rápida en Cuauhtémoc, Chihuahua, México. Se centra en los riesgos físicos asociados al trabajo repetitivo de las extremidades superiores. El objetivo principal del estudio fue analizar el nivel de riesgo ergonómico con la herramienta de Evaluación de tareas repetitivas (Assessment of Repetitive Tasks (ART™ Tool)), y, a partir de ahí, aplicar intervenciones ergonómicas y organizativas que fueran sencillas y de bajo costo para ver si realmente hacían diferencia. Entre los objetivos más concretos destacaron: detectar las tareas repetitivas que resultaban más críticas y las posturas que generaban mayor problema, aunque el análisis se limitó estrictamente a las actividades de preparación y cocción de alimentos, dejando fuera otras áreas como el servicio o lo administrativo. Para llevarlo a cabo se optó por un enfoque descriptivo con mediciones antes y después, siempre desde la visión del sistema de trabajo completo (considerando la tarea, al trabajador, las herramientas y el espacio disponible). La herramienta ART Tool permitió medir de forma cuantitativa la exposición a elementos clave: la repetición constante, la fuerza aplicada, las posturas incómodas y los periodos de recuperación insuficientes.

Lo anterior se apoyó con observaciones directas en el lugar, análisis detallado de los ciclos de cada tarea, fotos y un modelado panorámico 3D del sistema hombre-máquina usando el software Autodesk Revit y técnicas paramétricas de BIM para simular las interacciones. Con base en lo observado, se aplicaron cuatro medidas integradas y prácticas: primero, se colocaron tapetes ergonómicos antifatiga en las zonas donde se pasa mucho tiempo de pie; segundo, se implementa la metodología 5S para ordenar y mantener el puesto de trabajo; tercero, se ajustaron las alturas de las mesas de preparación según las medidas antropométricas reales de los trabajadores; y cuatro, se instalaron estanterías a alturas más adecuadas, lo que ayudó a disminuir los alcances por encima del hombro y las flexiones incómodas del tronco.

Palabras Claves: Análisis ergonómico, cocina de restaurante, herramienta artística, AutoDesk Revit, diseño de modelos 3D

Relevancia para la ergonomía: Se contribuye a la ergonomía ocupacional y a la evaluación del trabajo al demostrar un enfoque replicable orientado a la decisión que integra la evaluación observacional estandarizada ART Tool con controles de ingeniería y organización de bajo coste. El estudio vincula las puntuaciones medibles de exposición con acciones prácticas de rediseño (tapete ergonómico, 5S, estantería, apoyando la planificación de intervenciones informada por riesgos en pequeñas operaciones de servicios de alimentación.

Abstract: This chapter describes an ergonomic assessment performed in the kitchen of a fast-food restaurant in Cuauhtémoc, Chih. It focuses primarily on the physical risks associated with repetitive upper extremity work. The main objective of the study was to analyze the level of ergonomic risk with the Assessment of Repetitive Tasks tool (ART Tool), and from there, to apply ergonomic and organizational interventions that were simple and low-cost to see if they really made a difference. Among the most specific objectives were to detect the repetitive tasks that were most critical and the postures that generated the greatest problem, although the analysis was strictly limited to food preparation and cooling activities, leaving out other areas such as service or administration. To carry it out, a descriptive approach was chosen with before and after measurements, always from the vision of the complete work system (considering the task, the worker, the tools and the available space). The ART Tool made it possible to quantitatively measure exposure to key elements: constant repetition, applied force, awkward postures and insufficient recovery periods.

This was supported by direct on-site observations, detailed analysis of the cycles of each task photos and three-dimensional panoramic modeling of the human-machine system using Autodesk Revit software and parametric BIM techniques to simulate the interactions. Based on what was observed, four integrated and practical measures were applied: first, ergonomic anti-fatigue mats were placed in the twelve areas where a lot of time is spent standing; second, the 5S methodology is implemented to organize and maintain the workplace; third, the heights of the preparation tables were adjusted accordingly to the actual worker's anthropometric measurements; and four, shelves were installed at more suitable heights, which helped to reduce over the shoulder reaches and uncomfortable trunk flexions.

Keywords: Ergonomic Analysis, Restaurant Kitchen, Art Tool, AutoDesk Revit, 3D Model Design

Relevance to Ergonomics: This case contributes to occupational ergonomics and work evaluation by demonstrating a replicable, decision-oriented approach that integrates standardized observational assessment (ART Tool) with low-cost engineering and organizational controls. The study links measurable exposure

scores to practical redesign actions (mats, 5S, shelving), supporting risk-informed intervention planning in small food-service operations.

1. INTRODUCTION

Fast-food kitchens are demanding work systems in which repetitive upper-limb actions, prolonged standing, trunk flexion, reaching, constrained workspaces, thermal stressors, time pressure, and frequent interactions with tools and storage surfaces converge in short production cycles. These conditions make kitchen work highly relevant to occupational ergonomics and, more specifically, to work evaluation approaches that seek to connect observable exposure patterns with practical redesign decisions. Recent evidence continues to show that food-service workers experience substantial musculoskeletal burden. In Egypt, Abdelsalam et al. (2023) reported that 90.6% of kitchen workers had work-related musculoskeletal disorders during the previous 12 months, with the lower back, knees, feet, neck, and shoulders among the most affected regions. In hospitality kitchens in Ethiopia, Abebaw et al. (2024) found that prolonged standing and arm overreaching were significant determinants of WMSDs. In Ontario, Canada, Yates and Brown (2025) reported musculoskeletal discomfort in 98.1% of food-service kitchen workers and noted that many workers spent much of the shift standing, had limited breaks, and worked at non-ideal workstation heights. Taking together, these studies indicate that kitchen tasks should not be treated as ordinary service activities, but as exposure-intensive work processes in which cumulative physical demand can be systematically evaluated and reduced.

This context is especially important for small and medium-sized food operations, where productivity targets are often met through informal workflow adaptations rather than formally designed ergonomic controls. In such settings, repetitive preparation and cooking tasks are commonly performed under conditions of asymmetric reaching, repeated gripping, insufficient recovery, and awkward postures generated by poorly positioned ingredients, utensils, and storage surfaces. Leong et al. (2024) showed that musculoskeletal symptoms affected 53% of hospital food-service workers in a tertiary-care setting, and that staff whose duties involved cooking and food preparation were at higher risk of injury or musculoskeletal symptoms than those in administrative roles. These findings reinforce the view that kitchen risk is linked not only to task repetition itself, but also to the organizational and spatial conditions under which repetition occurs. Therefore, ergonomic assessment in kitchens should extend beyond symptom description and include structured evaluation of task mechanics, work pacing, reach geometry, and the physical arrangement of the workstation.

Within this framework, the Assessment of Repetitive Tasks (ART) tool remains particularly relevant. According to the UK Health and Safety Executive, ART is designed to assess repetitive tasks involving the upper limbs and focuses on common risk factors that contribute to upper-limb disorders, including repetition, force, awkward postures, and related task conditions (Health and Safety Executive [HSE], 2023). This makes ART especially appropriate for fast-food kitchen activities such as chopping, assembling, reaching for ingredients, transferring containers,

handling utensils, and working at preparation tables, because these operations often combine rapid cycle times with repeated arm and wrist actions and intermittent trunk and shoulder loading. For work-evaluation purposes, ART is valuable because it converts observation into a structured exposure score that can guide prioritization, comparison across task elements, and post-intervention reassessment. In other words, it supports decision-making rather than merely describing posture in qualitative terms.

The value of ART is reinforced by recent developments in ergonomic assessment science. Although the present chapter uses a standard observational approach, the broader literature shows a clear trend toward integrating conventional risk-assessment tools with digital or semi-automated evaluation systems. Recent ergonomics research has also emphasized that observation-based tools remain useful when they are embedded in broader intervention frameworks that connect measured exposure to redesign actions, training, and implementation strategy. This is consistent with the logic of work evaluation in occupational ergonomics: the objective is not only to identify risk, but to support feasible changes in the real work system. In that sense, structured observational tools such as ART retain practical value precisely because they can be interpreted alongside spatial, organizational, and anthropometric information rather than being used in isolation.

For that reason, the use of a three-dimensional digital model in this chapter is methodologically significant. Human-centered digital-twin literature increasingly argues that digital counterparts of workplaces can support more intuitive management of complex human-machine-environment interactions and allow decision-makers to compare scenarios before physical implementation. Krupas et al. (2024) describe human-centric digital twins as an enabling route for applications that place the worker at the center of the system rather than optimizing productivity alone. Likewise, Battini et al. (2024) explain that Industry 5.0 has strengthened interest in human-centered system architectures in which digital representations support decisions at strategic, technical, and operational levels. Although the present study uses Autodesk Revit and a practical BIM-oriented modeling strategy rather than a fully sensorized digital twin, its logic is aligned with this human-centered trend: the model is used to understand constraints, test layout alternatives, and verify whether proposed controls are compatible with real spatial conditions. This is highly relevant in kitchens, where small dimensional mismatches can generate repeated overreaching, trunk flexion, congestion, and avoidable extra handling.

Another reason this integrated approach is important is that many of the most useful ergonomic controls in food-service operations are relatively low-cost but depend on accurate diagnosis. Recent evidence suggests that risk in kitchen work is strongly influenced by long standing times, limited recovery opportunities, and suboptimal workstation configuration (Abebaw et al., 2024; Yates & Brown, 2025). In parallel, evidence from prolonged-standing occupations indicates that anti-fatigue floor mats can reduce pain and fatigue, support their use when stand duration cannot be eliminated entirely (Ünver & Orğan, 2023). Similarly, improved storage positioning, more appropriate surface heights, and better task organization can reduce excessive reaches and awkward trunk or shoulder postures before more expensive engineering changes are considered. Therefore, the combination of

observational assessment with spatial simulation and practical organizational redesign is highly appropriate for the work-evaluation theme of this chapter.

Based on this background, the present study addresses an important applied ergonomics problem: how to identify, quantify, and reduce repetitive-task exposure in a fast-food kitchen without requiring major structural reconstruction. The chapter evaluates the kitchen using the ART tool, interprets the initial exposure pattern from a work-system perspective, and then examines the likely effect of low-cost ergonomic and organizational interventions supported by a three-dimensional model of the human-machine-workspace interaction. In doing so, it contributes to occupational ergonomics by showing how standardized observational assessment, anthropometric adjustment, spatial redesign, and basic organizational controls can be combined into a practical intervention pathway for small food-service environments.

2. OBJECTIVE AND DELIMITATIONS

2.1 General objective

To perform an ergonomic work evaluation of a fast-food restaurant kitchen using the ART™ Tool and to assess the impact of targeted ergonomic interventions.

2.1.1 Specific objectives

- (1) Identify critical repetitive tasks and postures.
- (2) quantify baseline ergonomic risk.
- (3) implement low-cost ergonomic and organizational interventions; and
- (4) estimate the reduction in ergonomic risk after intervention.

2.2 Scope and Delimitation

The study was limited to food preparation and cooking tasks in a single fast-food restaurant kitchen located in Cuauhtémoc, Chihuahua, Mexico. Administrative activities, customer service, and psychosocial risk assessment were excluded. The evaluation focused on physical ergonomic risk associated with repetitive upper-limb work.

3. METHODOLOGY

A descriptive, standards-oriented work evaluation with a before-and-after design was conducted. The evaluation followed the work-system perspective (task–worker–tools–workspace) and applied the HSE ART™ Tool to quantify exposure associated with repetition, force, awkward postures, and recovery. Direct observation, task cycle analysis, and photographic documentation supported the identification of critical tasks and the prioritization of controls (Figure 1).



Figure 1. Kitchen original layout

4. RESULTS

A baseline assessment using the HSE ART Tool was done, (Figure 2). The initial scores were 12.75 for the left upper limb and 22.5 for the right upper limb, indicating medium-to-high ergonomic risk requiring urgent further investigation and intervention to lower the ergonomic risk level.

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The ART tool

Stage A Frequency/repetition

START

A1 Arm movements

	Left	Right
Infrequent (eg some intermittent movement)	G 0	G 0
Frequent (eg regular movement with some pauses)	A 3	A 3
Very frequent (eg almost continuous movement)	R 6	R 6

A2 Repetition

	Left	Right
Similar motion patterns repeated 10 times per minute or less	G 0	G 0
Similar motion patterns repeated 11 to 20 times per minute	A 3	A 3
Similar motion patterns repeated more than 20 times per minute	R 6	R 6

Stage B Force

	Left	Right
See grid on page 5 of the assessment guide	G 0	G 0
See grid on page 5 of the assessment guide	A 1-4	A 1-4
See grid on page 5 of the assessment guide	R 6-12	R 6-12

Stage C Awkward postures

C1 Head/neck posture

	Left	Right
Almost neutral	G 0	G 0
Bent or twisted part of the time	A 1	A 1
Bent or twisted more than half of the time	R 2	R 2

C2 Back posture

	Left	Right
Almost neutral	G 0	G 0
Bent forward, sideways or twisted part of the time	A 1	A 1
Bent forward, sideways or twisted more than half of the time	R 2	R 2

C3 Arm posture

	Left	Right
Elbow close to the body or the arm is supported	G 0	G 0
Elbow raised away from the body part of the time	A 2	A 2
Elbow raised away from the body more than half of the time	R 4	R 4

C4 Wrist posture

	Left	Right
Almost neutral/straight	G 0	G 0
Bent or deviated part of the time	A 1	A 1
Bent or deviated more than half of the time	R 2	R 2

C5 Hand/finger grip

	Left	Right
Power grip or no awkward grip	G 0	G 0
Pinch or wide finger grip for part of the time	A 1	A 1
Pinch or wide finger grip for more than half of the time	R 2	R 2

Stage D Additional factors

D1 Breaks

	Left	Right
Less than 1 hour of continuous work	G 0	G 0
1 to less than 2 hours of continuous work	A 2	A 2
2 to less than 3 hours of continuous work	R 4	R 4
3 to less than 4 hours of continuous work	R 6	R 6
4 or more hours of continuous work	R 8	R 8

D2 Work pace

	Left	Right
Never difficult to keep up with the work	G 0	G 0
Sometimes difficult to keep up with the work	A 1	A 1
Often difficult to keep up with the work	R 2	R 2

D3 Other factors

	Left	Right
No factors present	G 0	G 0
1 factor present	A 1	A 1
2 or more factors present	R 2	R 2

D4 Duration

	Left	Right
Less than 2 hours	x 0.5	x 0.5
2 to less than 4 hours	x 0.75	x 0.75
4 to 8 hours	x 1	x 1
More than 8 hours	x 1.5	x 1.5

Summary

Stage	Score
Stage A Frequency score	A1 + A2 = 3 + 9 = 12
Stage B Force score	B = 1 + 4 = 5
Stage C Posture score	C1 + C2 + C3 + C4 + C5 = 7 + 11 = 18
Stage D Additional factors	D1 + D2 + D3 = 6 + 6 = 12
Task score	17
Duration	0.75
Exposure score	12.75 (Left hand), 22.5 (Right hand)

Figure 2. Art™ Tool initial results (HSE, 2023).

Using the Autodesk Reddy™ software a 3D model of the man-machine system was made. A parametric Building Information Modeling (BIM) approach was used. The kitchen was modeled at the level of detail required for ergonomics: architectural boundaries, fixed constraints, equipment geometry, and worker anthropometry.

Revit families were created or adapted for key kitchen assets (prep tables, shelving, refrigeration, cook line, hood) to preserve real dimensions and allow rapid repositioning during scenario testing (Figure 3).

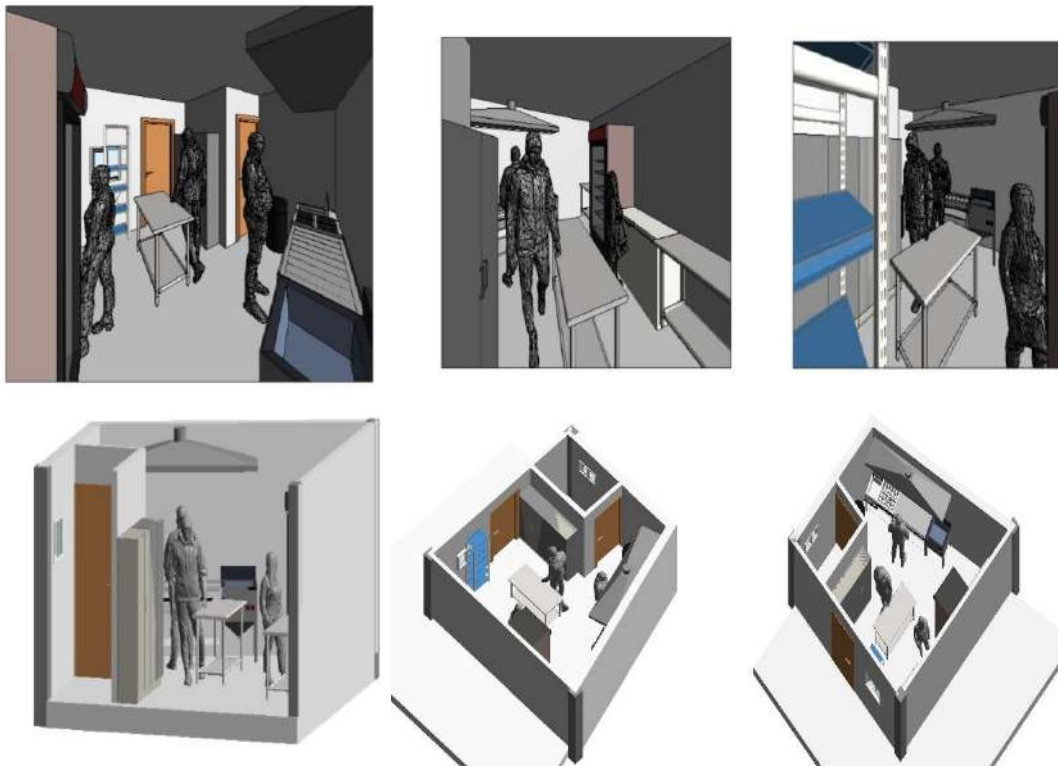


Figure 3. Kitchen layout and task interaction used for ergonomic analysis (3D model views).

Revit-based simulation was used as a structured way to explore interactions between the worker (human), the tools/equipment (machine), and the built environment (infrastructure). The model supported scenario comparison by allowing rapid repositioning of shelves and supplies, testing alternative station arrangements, and verifying that each proposal remained compatible with fixed constraints. The analysis focused on interaction mechanisms directly linked to ergonomic risk: reach distance, posture demand, walking paths, and cross-traffic conflicts during peak production.

- Station definition: prep, cook, assembly, and cold storage zones were delineated to reduce unnecessary walking and task fragmentation.
- Flow evaluation: typical paths between refrigerator-prep-cook-assembly were reviewed to identify congestion and crossing trajectories.
- Access to storage: shelving placement was optimized to reduce overhead reach and bending to low storage.
- Space for two-person work: clearances were evaluated where simultaneous work occurs (e.g., cook line and prep table adjacency).

The digital model directly informed four integrated interventions aligned with ergonomic work evaluation logic (hazard identification, control selection, and feasibility verification): (1) anti-fatigue ergonomic mats; (2) 5S implementation; (3)

Work surfaces and storage heights modification in relation to worker's anthropometric dimensions and (4) installation of shelving to reduce reaching and trunk flexion. Revit supported these proposals by quantifying reach distances and clearances and by validating that improved organization could be sustained through defined storage locations and visual management.

Following the implementation of anti-fatigue ergonomic mats, 5S workplace organization, tables height modification in relation to worker's anthropometric measurements, and height-appropriate shelving, the post-intervention ART Tool reassessment demonstrated a quantifiable reduction in exposure (Table 1). These controls targeted root causes identified in the work evaluation: unnecessary travel/handling, excessive reaches, and trunk flexion during ingredient retrieval, as well as insufficient micro-recovery during peak production.

Table 1. ART Tool exposure scores pre- vs post-intervention (ergonomic mats + 5S + preparation tables height + shelving).

Metric	Pre	Post	Change
Exposure score (Left upper limb)	12.75	11.00	-13.7%
Exposure score (Right upper limb)	22.50	19.00	-15.6%
Primary drivers reduced	High reaching, trunk flexion, limited recovery	Reduced reaches/flexion; improved flow and recovery	≥10% risk reduction achieved

The ART Tool baseline showed higher exposure to the right upper limb than the left, consistent with asymmetric task demands during food preparation. The digital model supported control selection by identifying which reaches and postures were driven by layout and storage height rather than by the task itself. By reducing reach distances, limiting trunk flexion, and improving organization and pacing through 5S, the post-intervention scenario was projected to achieve at least a 10% reduction in ART exposure scores, meeting the project target and equally importantly increasing labor productivity. This strengthens the work evaluation narrative by connecting observable task mechanics to design controls validated in a virtual environment.

5. CONCLUSIONS

This study shows that repetitive food-preparation and cooking tasks in a fast-food kitchen can generate meaningful ergonomic exposure even when the workplace appears operationally functional. From a work-evaluation perspective, the most important contribution of the chapter is not only the identification of elevated ART scores, but the demonstration that these scores can be connected to specific, modifiable features of the work system. The baseline assessment suggested that exposure was shaped by a combination of repetitive upper-limb activity, awkward

posture, reach-related inefficiencies, and limited recovery opportunities. This interpretation is consistent with recent evidence showing that kitchen workers are routinely exposed to high musculoskeletal burden linked to prolonged standing, overreaching, demanding preparation duties, and non-ideal workstation conditions (Abebaw et al., 2024; Leong et al., 2024; Yates & Brown, 2025).

The chapter also supports the practical usefulness of the ART tool in food-service ergonomics. ART was originally developed for repetitive upper-limb work, and the current application confirms that it is suitable for structured assessment of kitchen activities in which arm movement, hand use, trunk posture, and recovery are tightly interrelated. Because ART generates interpretable exposure scores, it provides a rational basis for prioritizing interventions and comparing pre- and post-intervention conditions (HSE, 2023). In the present manuscript, this was especially relevant for distinguishing the higher exposure of the right upper limb and for translating observational findings into intervention targets. Rather than treating ergonomic assessment as an isolated audit exercise, the study used ART as a decision-support tool, which is precisely how work-evaluation methods create value in applied settings.

A further strength of the study is the use of three-dimensional modeling to support intervention design. The Revit-based model made it possible to examine the kitchen as an integrated work system and to test changes in storage location, work-surface relationship, spatial compatibility, and worker interaction before or alongside physical implementation. While this approach is more modest than a real-time human digital twin, it is conceptually consistent with current human-centered digital modeling research, which emphasizes the value of digital counterparts for understanding task-environment interactions and improving work design under Industry 5.0 principles (Battini et al., 2024; Krupas et al., 2024). In practical terms, the digital model strengthened the credibility of the redesign by showing that the proposed controls were not generic recommendations, but layout-sensitive solutions grounded in the actual kitchen geometry.

The selected controls—anti-fatigue mats, 5S-based workplace organization, anthropometrically informed table-height adjustment, and more suitable shelving heights—represent a realistic intervention package for small food-service operations. Their importance lies in the fact that they target root exposure drivers rather than isolated symptoms: mats address prolonged standing discomfort, organization reduces unnecessary handling and search time, surface-height adjustment improves the relationship between worker stature and task plane, and better shelving reduces shoulder elevation and trunk flexion. This combination reflects an intervention logic widely recommended in ergonomics: when major capital redesign is not feasible, meaningful exposure reduction can still be achieved through coordinated engineering and organizational improvements. Evidence from prolonged-standing contexts also supports the inclusion of anti-fatigue mats as part of this package (Ünver & Orğan, 2023).

At the same time, the conclusions should be interpreted within the study's scope. The work was limited to one fast-food kitchen and focused on physical risk associated with repetitive upper-limb work, without addressing psychosocial load, thermal exposure in detail, or long-term clinical outcomes. In addition, post-

intervention conclusions are based on practical before-and-after work-evaluation logic rather than a large experimental trial. Therefore, the findings should be understood as strong applied evidence for local redesign rather than universal estimates of effect size. Even so, this does not weaken the value of the chapter; on the contrary, it underscores its relevance as an ergonomics case study for intervention planning in real service environments.

Overall, the chapter contributes to occupational ergonomics and to the evaluation of work by demonstrating that a fast-food kitchen can be systematically assessed as a repetitive-task system and improved through feasible, low-cost redesign. The results support a clear conclusion: kitchen risk is not inherent only to the task itself, but also to how the task is spatially arranged, organized, and supported by the built environment. Consequently, even modest changes in layout, storage, standing support, and workstation height can produce measurable reductions in ergonomic exposure when they are guided by a structured assessment tool and verified through three-dimensional modeling. Future research should extend this line of work by combining ART with direct biomechanical or time-motion measures, multi-site samples, and longitudinal follow-up to better quantify how ergonomic redesign affects both musculoskeletal risk and operational performance in food-service systems.

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USABILITY IN ADMINISTRATIVE DOCUMENTATION: A CASE STUDY ON INDUSTRIAL ENGINEERING COORDINATION

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Resumen: La presente aplicación fue realizada en una institución de educación superior localizada en Tijuana, México. Particularmente, ésta fue enfocada en mejorar el proceso administrativo cambio de especialidad a través de su rediseño y uso de formatos utilizados alineados al proceso en cuestión. Las mejoras fueron realizadas mediante la utilización de ergonomía cognitiva, particularmente consideraciones del enfoque de usabilidad; es decir, el mejoramiento de la experiencia en el proceso administrativo incluía su documentación. Esto implicó el uso de la metodología que exhibió una muestra de los potenciales usuarios de dicho proceso y sus formatos. Técnicas cualitativas y cuantitativas fueron empleadas para obtener información de la experiencia de los usuarios, la cual fue realizada antes y posterior a su mejora. La contemplación de aspectos éticos y de confidencialidad fueron considerados y aplicados dentro de dicha metodología. Asimismo, factores cognitivos fueron destacados como elementos principales a valorar dentro de las mejoras. Los resultados obtenidos exhibieron que el tiempo de interpretación y llenado de los formatos empleados fue reducido y los errores cometidos en su llenado fueron disminuidos. Consecuentemente, la experiencia o satisfacción del usuario fue incrementada en el proceso administrativo considerado. El uso de su documentación fue incluido. Finalmente, esto permitió comprobar los beneficios a partir de la utilización del enfoque de usabilidad dentro del proceso administrativo estudiado y en la documentación empleada.

Palabras Clave: Usabilidad, documentación administrativa, coordinación, licenciatura, Ingeniería Industrial

Relevancia para la Ergonomía: Este proyecto representa la solución práctica y eficaz a un problema concreto dentro del proceso administrativo cambio de especialidad. Este es llevado a cabo en los estudios de licenciatura dentro de una institución de educación superior. Para ello, ergonomía cognitiva y el enfoque de usabilidad fueron usados para mejorar dicho proceso administrativo y la documentación empleada. De la misma forma, este proyecto aporta valor académico y profesional al generar conocimiento aplicable en el campo de la ergonomía cognitiva y la usabilidad. Esto es por las consideraciones técnicas y metodológicas alineadas al logro de sus objetivos; además, éste aporta colaboración en el diseño de sistemas administrativos centrados en el usuario para mejorar su experiencia. Asimismo, la contribución trasciende, similarmente, al ámbito institucional posicionándose como un ejemplo. Esto es través de cómo la investigación bien dirigida puede generar impactos positivos y medibles en un ambiente académico.

Abstract: This project was conducted at a higher education institution in Tijuana, Mexico. Specifically, it focused on improving the administrative process for changing majors through redesign and the use of forms tailored to that process. The improvements were made using cognitive ergonomics, particularly considerations of the usability approach; that is, the improvement of the experience in the administrative process included its documentation. This used a methodology that included a sample of potential users of mentioned process and its forms. Qualitative and quantitative techniques were employed to obtain information on the user experience, which was assessed both before and after the improvements. Ethical and confidentiality considerations were taken into account and applied within this methodology. Additionally, cognitive factors were highlighted as key elements to evaluate within the improvements. The results showed that the time required to interpret and complete the forms was reduced, and errors in their completion were minimized. Consequently, user experience and satisfaction were enhanced in the administrative process under consideration. The documentation was included. Finally, this allowed to verify the benefits of applying the usability approach to the administrative process studied and the documentation used.

Keywords: Usability, administrative documentation, coordination, bachelor's degree, Industrial Engineering

Relevance to Ergonomics: This project offers a practical and effective solution to a specific problem in the administrative process of changing majors. It was carried out in undergraduate programs at a higher education institution. Cognitive ergonomics and a usability approach were used to improve the process and documentation. The project adds academic and professional value by generating knowledge in cognitive ergonomics and usability. This results from technical and methodological considerations aligned with its objectives. It also helps design user-centered administrative systems to enhance the user experience. The contribution extends to the institution by serving as an example of how targeted research can create positive and measurable impacts in an academic environment.

1. INTRODUCTION

This study addresses a significant issue in academic and administrative area at a TecNM institute. It focused on the usability of documentation used in the major change process for the Bachelor's Degree in Industrial Engineering. Students may request a change of major during the sixth semester for personal or professional reasons. This process involves the program coordinator, the assistant and head of the Department of Industrial Engineering, and the assistant from the Office of Academic Services assigned to the bachelor program. The process is typically carried out in the eighth or ninth semester and occurs across all 22 bachelor's programs at the institute. The administrative process affects internal performance and the user experience, especially for Industrial Engineering students. Addressing this issue is important to strengthen administrative management with innovative approaches suited to this context. Improvements can be replicated across programs to support administrative management for students' needs.

For students in the Industrial Engineering Bachelor's Program, the coordination of the program served 1,800 students each semester. It was divided into morning and afternoon sections to provide better services to students. The morning section served students from first to fifth semesters. The afternoon section served those from the sixth to the twelfth semesters. Although the project refers to the coordination of the Industrial Engineering Program, it focused mainly on the afternoon section. The morning program supported the afternoon program by validating the research process, improving procedures and documentation, and confirming project results.

The project began by identifying the different conditions of the major change process. Two perspectives were examined: the user's experience and the process's objective in serving users. Thirty-five surveys were administered to students who requested a major change during August–December 2023. Seven surveys went to participants in administrative and support roles. Two surveys were completed by two faculty members coordinating in the past the afternoon section, and five surveys, by administrative members.

The surveys done by the 35 students gathered information such as the date of the process, gender, current semester, and age. They also asked about waiting times, the time needed to complete forms, and the duration of assistance from the coordination office. The survey evaluated user experience and satisfaction with the process and forms. It covered clarity, comprehensibility, structure, organization, ease of use, design, format, effectiveness, and reliability. Moreover, it measured overall user satisfaction, number and types of errors while completing forms, and gathered suggestions for improvement.

Furthermore, the surveys conducted with the seven administrative members focused on obtaining information such as: length of service in the role; primary administrative responsibilities; clarity and readability of the information provided in the forms; organization and structure of the form; ease of transcription and processing; common errors and omissions made; impact on the administrative workload; overall satisfaction; number of errors or omissions made; and suggestions for improving the process and the forms used. In particular, the assistant from the

Department of Industrial Engineering, the afternoon section coordinator, and two faculty members who served as afternoon section coordinators participated in interviews regarding to improve the process and the forms used. This was done to gather information from their experiences with the major change process during the past and current periods.

Additionally, the LUSWV checklist (Hernández-Escobedo *et al.*, 2018) was used to evaluate the usability of the two forms used in the process. This checklist assesses the forms in phases, which are named: orientation, key questions, contextualization, criteria, information and resources, request and comments, achievements, evaluation, benefits, and comparison. Furthermore, each phase is evaluated by confirming or excluding each criterion that comprises it. Phase 1 consisted of five criteria; Phase 2, eight criteria; Phase 3, three criteria; Phase 4, seven criteria; Phase 5, three criteria; Phase 6, two criteria; Phase 7, four criteria; Phase 8, two criteria; Phase 9, six criteria; and Phase 10, two criteria (Hernández-Escobedo *et al.*, 2018). A total of 42 criteria are assessed in the guide. The results obtained are presented in the following paragraph, and in Section 4, two experiences are considered and examined.

With regard to the user experience, it was noted that the process and its documentation lacked clarity and were difficult to use for the various stakeholders. The difficulties reported by the 35 users during the August–December 2023 semester were: errors in interpreting the information; the time required to complete the forms and/or the entire process; dissatisfaction with the user experience during the process; and the total duration of the process. In addition, the process consisted of 18 steps and began with the student contacting the coordination office, filling out forms, verifications and inspections in the school's control system, the generation of additional documents by the Department of Industrial Engineering, among other steps, accumulating 46 minutes until the system was verified by the Assistant in the Department of Industrial Engineering. She confirmed that the request had been transferred to the Department of School Services for confirmation, validation, authorization, and notification to all parties involved. It included the student who verifies the change in the school control system. The total time increased because the School Services Department conducts its activities one week after the application deadline for the process, which was finalized by the Assistant in the Department of Industrial Engineering.

On the other hand, with regard to the process's objective in serving users, a usability approach was employed to validate user interaction with the system through the formats used and interpersonal relationships with the identified stakeholders. Their main observations are as follows: 1. Lack of clear objectives. The documentation design lacked a defined purpose and was not aligned with user needs and coordination processes; 2. Inconsistency in design. The lack of standardized criteria led to variability in the quality and presentation of information within the documentation used; 3. Legibility and comprehension issues. The use of excessive technical language, inappropriate font sizes, and low-contrast colors complicated interpretation; 4. Lack of feedback in the design. The documentation development did not involve end users, and therefore, the real needs of the environment were not incorporated into the design; 5. Psychological and

sociocultural factors were not considered. Users' cognitive abilities and diversity (customs, habits, and levels of experience) were not taken into account. These observations directly affected the main difficulties identified: errors in interpreting the information; the time required to complete the forms and/or the process; dissatisfaction with the experience of carrying out the process; and the total time spent on the process. Likewise, the timeframe specified by the Department of Student Services for completing the process was included. This department limited the time spent assisting users and verified the overall process and the documentation generated. Subsequently, the department updated the student management system accordingly and assigned the student to the major selected in the submitted application.

The following sections present the objective, theoretical background, methodology, results, and conclusions.

2. OBJECTIVE

To verify the usability of the major change process and the documentation used in the Industrial Engineering program, using cognitive ergonomics tools and methodologies to evaluate the user experience metrics of said process.

3. BACKGROUND

This section presents relevant aspects of cognitive ergonomics, usability, and its impact, and cognitive ergonomics techniques and tools.

3.1 Application of Cognitive Ergonomics in Documentation

Cognitive ergonomics has direct applications in the design and evaluation of documentation. Well-designed documentation, from a cognitive perspective, facilitated understanding, reduced errors, and improved user satisfaction because it incorporated these principles, thereby facilitating its evaluation, as outlined below:

- a. Designing usable documents. This involves applying principles of cognitive ergonomics to ensure that information was easy for users to find, understand, and use. Redish (2010) emphasized the importance of considering users' cognitive needs when designing documents. Moreover, Tullis and Albert (2013) listed key principles for achieving usable document design. In professional practice, applying these principles meant structuring information logically, using clear language, and avoiding unnecessary jargon to facilitate reading and comprehension.
- b. Principles of graphic and visual design. This is relevant to the usability of documentation. Effective visual design improves readability, highlights important information, and facilitates understanding. Williams (2014) described how graphic design principles improve the organization and readability of documents.

Additionally, Mayer (2009) highlighted the value of visual elements for understanding complex information. In professional practice, documentation designers carefully should consider typography, white space, color selection, and the inclusion of visual elements to create documents that are attractive and user-friendly.

- c. Document usability evaluation. Evaluating document usability was essential to ensure they meet users' needs. Various evaluation techniques were used to identify problems and thereby improved the quality of the documentation. Schriver (1997) mentioned several techniques for evaluating document usability, including user testing and heuristic evaluations. On the other hand, Weiss (2005) emphasized the importance of user feedback. In professional practice, the evaluation of documentation usability was carried out by observing how users search for information, measuring the time they take to complete tasks, or collecting their opinions and suggestions.

3.2 Fundamentals of Usability

Usability was a central concept in the design of interactive products and systems. This concept also referred to the ease with which users achieve their goals when using a product or system. Understanding the fundamentals of usability is essential for creating effective and efficient interfaces, which are presented below:

- a. Usability Concepts. The concept of usability encompassed multiple dimensions that determine the quality of the user experience. These dimensions included learnability, efficiency, memorability, error prevention, and user satisfaction. The definition in ISO 9241-11:2018 (2018) provided a formal framework for understanding usability, emphasizing effectiveness, efficiency, and satisfaction in a specific context. Furthermore, Nielsen's five attributes (1993) offered a detailed view of the aspects that contribute to a system's usability. These fundamental concepts guided professional practice. This was because they provided clear criteria for evaluating and improving the quality of user-system interaction.
- b. Principles of user-centered design (UCD). This design approach was an iterative process that centers users' needs, desires, and limitations. The application of UCD principles was crucial to ensuring the usability of products and systems. Abras et al. (2004) noted that UCD was a philosophy and a process that used research to inform user-centered design decisions. Additionally, Gould and Lewis (1985) highlighted two fundamental principles: understanding the user and iterative design. These principles were essential in professional practice. This was because they guided how designers approach the development of products and systems. Thus, this approach ensured that user needs were considered at every stage of the process.
- c. Factors Affecting Usability. Various factors can influence a system's usability. These ranged from user characteristics to aspects of interface design. Identifying and understanding these factors were fundamental to effectively address usability challenges. Bevan et al. (1991) provided a useful classification of

factors affecting usability. These factors included user characteristics, task factors, and system attributes, among others. Additionally, Schneiderman and Plaisant (2016) provided practical guidelines for interface design that can improve usability. In professional practice, designers should consider these various factors when creating and evaluating interactive systems to ensure an optimal user experience. For example, if the interface was simple and consistent, it would present information in a more organized manner and require less cognitive load (e.g., well-labeled buttons, immediate feedback). The product's usability would be enhanced.

3.3 Usability in Productivity and Satisfaction

Usability had a significant impact on users' productivity and satisfaction when interacting with systems and products. A usable design increased efficiency, reduced errors, and improved the overall user experience. That is:

- a. **The Relationship Between Usability and Productivity.** The relationship between a system's usability and its users' productivity were manifested in multiple ways. An easy-to-use system would allow users to complete their tasks quickly and with less effort. This would lead to increases in productivity. Nielsen (1993) explained how usability improves productivity by reducing time and errors. Likewise, Shackel (1991) noted that studies have demonstrated significant increases in productivity resulting from improvements in usability. In professional practice, investment in a usable design was justified by the return in terms of user efficiency and productivity. For example, high-usability management software reduced employees' mental load. This enabled more tasks to be completed correctly in less time, which was considered as a positive return on investment.
- b. **Measuring user satisfaction.** Satisfaction is an important indicator of the quality of the interaction experience. Measuring satisfaction helped to evaluate the success of a design and identify areas for improvement. Bevan (1995) defined user satisfaction and the factors that influence it. Additionally, Brooke (1996) discussed methods and tools for measuring satisfaction. In professional practice, the collection and analysis of user satisfaction data provided relevant information on the design's effectiveness from the user's perspective.
- c. **Strategies for improving usability.** Various strategies can be implemented to improve the usability of a system or product. This involved applying design principles, conducting user testing, and implementing iterative improvements. Gould and Lewis (1985) highlighted the importance of user-centered design, testing, and iteration. Additionally, Nielsen (1993) added training, documentation, and customization as key strategies. In professional practice, a combination of these strategies was essential to achieve significant improvements in usability, productivity, and user satisfaction.

3.4 Usability Evaluation

Usability evaluation was an essential component of the user-centered design process. It allowed for the identification of usability issues, the collection of user feedback, and the improvement of interface quality. There were various methodologies for evaluating usability, each with its own advantages and disadvantages, for example:

- a. Heuristic evaluation. This was a usability inspection method in which experts evaluate an interface against a set of general interface design principles, known as heuristics. Nielsen and Molich (1990) introduced heuristic evaluation as a method for identifying usability problems. Likewise, Nielsen (1994) popularized ten key heuristics that serve as guidelines for evaluators. In professional practice, heuristic evaluation was a relatively quick and cost-effective method for identifying usability problems early in the design process.
- b. Usability testing. This involved observing users as they interact with a system to identify problems and collect data on their experience. Rubin and Chisnell (2008) defined usability testing as a technique for observing users. Likewise, Dumas and Redish (1999) described the typical process and the types of data that can be collected. In professional practice, usability testing provided valuable insights into how users interact with a system. This allowed the identification of problems that may not be evident to designers or experts.
- c. Cognitive inspection methods. These methods were evaluation techniques that focus on analyzing the interface from the perspective of the user's cognitive processes. This was done to predict where difficulties might arise. Polson et al. (1992) introduced cognitive inspection methods as a way to simulate the user's thinking. On the other hand, Wharton et al. (1994) detailed the cognitive walkthrough, a specific method focused on learnability. In professional practice, these methods were useful for identifying problems in how users attempt to learn to use an interface, and for predicting potential errors based on their understanding of the tasks.

3.5 Cognitive Ergonomics Tools and Techniques

Usability engineering involved applying principles, methods, and tools to design, develop, and evaluate the usability of interactive systems. Various tools and techniques were available for professionals to use in this process. Some examples are:

- a. Task analysis methods. These were used to understand in detail how users perform their tasks. This included the steps, decisions, and knowledge involved. This understanding was fundamental to designing systems that effectively support users' needs. Beyer and Holtzblatt (1998) defined task analysis as the detailed study of how users work. Annett (2004) also mentioned various techniques for conducting this analysis. In professional practice, task analysis provided a solid foundation for design. This ensured that the system aligns with

users' needs and work processes. The goal was to optimize each subprocess, eliminate redundancies, and reduce human errors.

- b. Prototyping techniques. This was a fundamental technique in user-centered design. It allowed the creation of early versions of a system or interface to test and gather user feedback before final implementation. Löwgren and Stolterman (2007) described prototyping and its different levels of fidelity. Likewise, Nielsen (1993) highlighted the benefits of prototyping for early problem identification and the exploration of design alternatives. In professional practice, prototyping was an essential tool for iterative design. This facilitated the collection of early feedback and the continuous improvement of the system.
- c. Usability evaluation tools (e.g., LUSWV). Various software tools and specific techniques had been designed to support usability evaluation, such as the *Lund Usability Scale for Web-based Visualizations* (LUSWV). These tools helped evaluators conduct systematic analyses and collect quantitative data on usability. Lund (2002) described the LUSWV as a questionnaire for evaluating the usability of web visualizations. Additionally, Barnum (2020) mentioned other common tools used in usability evaluation. In professional practice, these tools provided objective data and additional insights that complement qualitative evaluation methods. This helped professionals make informed design decisions.

4. METHODOLOGY

The methodology employed takes an interpretive approach using qualitative and quantitative data across six stages, which are outlined below:

1. Problem definition. The quantification of the indicators revealed the following: multiple complaints were raised by students during the August–December 2023 semester and in previous semesters. They noted that the process was time-consuming, that errors occurred during completion, and that it was not well received. Therefore, various indicators were developed for quantification. During the aforementioned semester, 35 students, who went through this process, participated in the project.
2. Design of data collection tools. A fully participatory approach was used, meaning those directly involved in the process were included in this phase. Specifically, the approach involved students, administrative staff, organizational representatives, and the research team. Consequently, a data collection strategy was developed that incorporated validation and triangulation of the results obtained. This allowed for an objective understanding of what occurred in the process and of the expected and achieved outcomes. A survey was developed to gather information about students' experiences. Additionally, a survey and an interview were conducted to gather information from the administrative staff currently involved and from those who previously held responsibilities within the process. Furthermore, the LUSWV guide (Hernández-Escobedo *et al.*, 2018) was used to evaluate the usability of the forms used in the process (this activity was carried out by the research team).

Additionally, a form was developed to record observations and evaluations of the forms used in the process. The criteria used for the surveys, interviews, and observations were described in section 1, which presents the context and existing issues.

3. **Data collection and analysis for diagnostic purposes.** Surveys and various materials were used to obtain relevant information from each of the identified sources. Thirty-five students participated by completing an equal number of surveys. Additionally, seven administrative staff members participated by completing a similar number of surveys and interviews; this was done to confirm the information obtained from the surveys, organizational data, and observations. Furthermore, a research strategy combining qualitative and quantitative methods was employed. Observations were used to gather information on the specific experiences of students and staff as they interacted and carried out the process. Additionally, an exploratory evaluation was used to observe how students and administrative staff interact with the current forms without intervention. This helped to identify difficulties in using the format. Some examples included imprecise language, confusing fields, or vague response formats. Similarly, 15 organizational documents were reviewed and analyzed, and 40 pages of notes were taken based on the observations made. Subsequently, the collected information was analyzed using an interpretive approach, and it was found that the average time to complete the documentation was 4.9 minutes, the average number of errors made per student was 0.5, and user satisfaction was 3.5% on a scale of 1 to 5. Furthermore, the total process duration averaged 46 minutes. The measurement of the times for each activity was based on Niebel and Freivalds (2009) and followed the time measurement in work methods area. The information obtained and the research process involved consideration of ethical and confidentiality aspects at every stage and phase.
4. **Redesign Proposal.** The combination of these perspectives provided a comprehensive and detailed view of the major change process. The information obtained was essential for accurately diagnosing usability issues and developing solutions to improve the experience for both students and administrative staff. Consequently, the major change process consisted of 18 activities, averaging 46 minutes to complete. Consequently, six activities were merged with others, and the time required for authorization from various academic and administrative departments was added. This was because these steps were not previously accounted and must be considered due to administrative regulations. On the other hand, two forms were used within the process and were reduced to one. Each form had 10 fields, totaling 20, and the current form has 11 fields. This was because there was duplication of information, such as date, student name, ID number (student registration number), major, contact phone number, institutional email, name, and signature. The criteria used to develop the form were: visual organization and structuring of information; clarity in instructions and expectations; design and visual elements; logical sequence and workflow; specific

instructions and standardization; formality and document management; and legibility and visual attention management.

5. **Implementation.** This phase involved implementing the new form and process, which were developed in accordance with current administrative regulations. In addition, students and administrative staff were trained to complete the form and to follow the updated process for changing majors. This included developing the corresponding flowchart, and the form incorporated visual aids to assist its completion. The improvements were implemented based on the aspects outlined in Sections 1 and 4.3. The implementation took 20 working days, and two pilot tests were conducted to iteratively improve the form. The major change process was subsequently incorporated into the quality management system of the institute. This was done on a temporary basis, and it is expected to be declared a critical component of that system.
6. **Evaluation of results and feedback.** The evaluation was conducted after implementing improvements to the major change process and the form used. The process was verified during implementation, and no deviations were found. Therefore, the major change process was carried out in accordance with the generated process diagram. Likewise, student surveys were conducted as outlined in Sections 1 and 4, Part 3. Thus, 24 surveys were administered to students who underwent this process during the January–June 2024 semester. In addition, seven interviews and seven surveys were conducted with administrative staff in accordance with Section 1 and Part 3 of Section 4. Two faculty members who served as coordinators participated in the interviews and surveys. Furthermore, various observations were made to confirm the information provided by the different sources, as indicated in Part 3 of Section 4. The results of interest were the time required to complete the form used in the major change process, the number of errors made when filling out or submitting said document, and satisfaction with the experience of completing the major change process. It was important to note that the improvement process was described as a heuristic. This was because the improvement was achieved through iterations, such that the process diagram and the document used were adapted to meet user needs, as noted in Section 3.

5. RESULTS

The results obtained after the evaluation allowed us to determine the effectiveness of the improvement and its impact on the user experience in the following factors:

- a. **Time to complete.** This indicator evaluated user efficiency based on the average time required to fill out the form. Students took an average of 4.9 minutes in the previous version and 3 minutes in the improved version. The time reduction was 1.9 minutes (approximately 38%). This was a significant reduction, representing efficiency in the administrative process.

- b. Error rate. The indicator used in this category reflected the clarity and effectiveness of the form based on the frequency of errors made while filling it out. The previous version had an average of 0.5 errors per student, while the improved version reduced this to zero errors. This improved document streamlined the process and increased the accuracy of the information. This made the administrative staff involved in the process's work easier.
- c. User satisfaction. The indicator used in this category reflected users' subjective assessments of the usability, clarity, and effectiveness of the process and documentation. Students reported that their initial satisfaction level was 3.5 on a scale of 1 to 5, and after the improvements, it rose to 4.0 and showed a relevant increase in the user satisfaction index.

Furthermore, other results were not reported in this study. For example, the institutional scaling of the process's importance within administrative activities was considered a secondary result. In other words, the standardization of the process and its integration into the quality management system were outcomes that demonstrated the process's importance within the institution. Although this process has been partially integrated into that system, the duration of this designation will depend on administrative changes at the institution and will align with the new educational model implemented there.

6. CONCLUSIONS

The application of evaluation and redesign methodologies to the process and its documentation was grounded in principles of cognitive ergonomics and usability. This had demonstrated its theoretical and practical values in the present project. On the one hand, applying knowledge to improve the user experience during the major change process has been a professional achievement within the participating higher education institution. This was because the principles of usability and cognitive ergonomics created the opportunity to redesign the major change process and the documentation used. The improvements led to changes in the user experience, enhancing its perception or subjective evaluation. This was despite the fact that the process duration increased due to the incorporation of current regulations. On the other hand, the documentation was redesigned and evaluated using three indicators developed. These indicators were applied before and after the improvements. Completion time, error rate, and user satisfaction were the indicators used. The results of the evaluations conducted before and after the improvements clearly demonstrate the practical value of knowledge. This was observed in reduced completion time and completion errors, as well as increased user satisfaction, as noted in Section 5.

With regard to the theoretical value, the application of the principles of cognitive ergonomics and usability had provided an opportunity to generate methodological knowledge. This is because a specific methodology was developed to support the research, as outlined in Section 4. Six phases were required to evaluate the application of these principles within the participant institution. In

particular, the development, implicit improvement, and use of materials were fundamental components of this theoretical value. Besides, validating each part of the process and the materials using the guide for developing visual aids was the central part of the methodology. This was because the guide included a suggested methodology for outlining changes and improvements to visual aids, as well as a tool for evaluating and validating their usability. In other words, the guide served as both a methodology and an evaluation tool for assessing product usability. This confirmed its ease of use and its theoretical and practical value.

Similarly, it is important to note that, although the project has produced tangible benefits with both theoretical and practical values, there should be opportunities to replicate it in other contexts and in other processes carried out within the institution. In particular, the approach used should be applied to improve other processes involving student services and support. This would be intended to enhance the quality of these services in such contexts. On the other hand, the approach should be applied in other contexts where the products or services offered by for-profit or nonprofit organizations can be evaluated. Its use would create opportunities to increase efficiency by changing perceptions or subjective evaluations of products or services. Similarly, this should provide an opportunity to confirm the theoretical and practical value of the approach in contexts seeking to replicate the work done. Furthermore, other technologies should be evaluated under this approach, opening up new application options across different contexts.

7. ACKNOWLEDGMENTS

We would like to acknowledge the Tecnológico Nacional de México/Instituto Tecnológico de Tijuana, PRODEP, and SECIHTI for partially funding the study. We would also like to thank the participating organization for contributing to this study. The interpretations and views in this chapter, however, are solely those of the authors.

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PREDICTIVE ERGONOMIC RISK ASSESSMENT OF THE WRIST, FOREARM AND UPPER ARM USING WEARABLE IMUS AND RANDOM FOREST

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Resumen Los trastornos musculoesqueléticos (TME) de miembros superiores son problemas de salud ocupacional frecuentes, asociados con movimientos repetitivos, posturas mantenidas y posiciones articulares forzadas. Los métodos tradicionales de evaluación ergonómica, como el Rapid Upper Limb Assessment (RULA), dependen de observación y proporcionan únicamente estimaciones de riesgo retrospectivas. Este estudio tuvo como objetivo desarrollar y validar un sistema portátil basado en unidades de medición inercial (IMU) y un clasificador Random Forest para predecir el riesgo postural en los segmentos de la muñeca, antebrazo y brazo superior durante tareas ocupacionales repetitivas. Treinta y nueve participantes realizaron tareas estandarizadas mientras usaban IMUs en la muñeca, antebrazo y brazo superior derechos. Los ángulos posturales fueron preprocesados mediante ventanas deslizantes. Se entrenó y validó un modelo Random Forest con 100 árboles de decisión para clasificar las posturas en cinco niveles de riesgo (Riesgo 1-5). El análisis de distribución de riesgo postural mostró que el antebrazo presentó de forma consistente la mayor exposición a posturas de alto riesgo, mientras que la muñeca y el brazo superior mostraron riesgo moderado a bajo. El modelo alcanzó precisión superior al 90% en todos los segmentos, con alta sensibilidad, y F1-score, confirmando la identificación confiable de posturas de alto riesgo. El análisis de importancia de características destacó la pronación/supinación

del antebrazo, la flexión/extensión de la muñeca y el desplazamiento angular acumulativo como predictores claves. La evaluación de usabilidad con 39 participantes indicó que el sistema es cómodo, poco intrusivo y fácil de usar, con tolerancia prolongada de uso (>6 horas) y alta percepción de precisión de la retroalimentación. Estos resultados sugieren que el sistema es técnicamente confiable como viable para su implementación práctica, apoyando intervenciones ergonómicas preventivas. El estudio demuestra el potencial de los enfoques basados en sensores y aprendizaje automático para transformar la ergonomía ocupacional de una evaluación reactiva a una gestión de riesgos preventiva, mejorando la seguridad, el bienestar y la productividad de los trabajadores.

Palabras clave: Trastornos musculoesqueléticos, ergonomía predictiva, unidades de medición inercial, algoritmos de aprendizaje de máquina.

Relevancia para la ergonomía: El desarrollo de este sistema ofrece un enfoque adicional para evaluar tareas en ergonomía. Al emplear IMU portátiles, el sistema proporciona datos cuantitativos y en tiempo real sobre el movimiento articular, reduciendo la dependencia de métodos observacionales subjetivos y permitiendo una evaluación más precisa y reproducible de las posturas de la extremidad superior. La integración de algoritmos de aprendizaje automático (Random Forest) permite no solo la detección, sino también la predicción de posturas de alto riesgo, facilitando intervenciones proactivas antes de que ocurran trastornos musculoesqueléticos y transformando la ergonomía de una evaluación reactiva a una gestión preventiva. El sistema puede ofrecer retroalimentación a trabajadores y especialistas en ergonomía, apoyando la corrección de posturas riesgosas, la mejora continua del diseño de tareas y la seguridad ocupacional. El uso de sensores portátiles permite escalabilidad y adaptabilidad en diversos entornos de trabajo sin interrumpir los flujos normales, extendiendo la evaluación ergonómica más allá de laboratorios hacia contextos industriales reales. Además, los conjuntos de datos generados sobre la biomecánica de las extremidades superiores pueden dar soporte al diseño de estaciones de trabajo, y proporcionan una base para futuras investigaciones que integren tecnología portátil, modelado predictivo y monitoreo de la salud ocupacional. En general, este trabajo provee de una ayuda para la ergonomía al combinar tecnología de sensores con modelado predictivo para ofrecer un enfoque fundamentado, práctico y preventivo para la evaluación del riesgo postural, cerrando la brecha entre los métodos observacionales tradicionales y las soluciones modernas basadas en datos.

Abstract: Upper limb musculoskeletal disorders (MSDs) are prevalent occupational health problems associated with repetitive movements, sustained postures, and awkward joint positions. Traditional ergonomic assessment methods, such as the Rapid Upper Limb Assessment (RULA), rely on observational evaluation and provide only post-hoc risk estimation. This study aimed to develop a wearable system using inertial measurement units (IMUs) and a Random Forest classifier to predict segment-specific postural risk in the wrist, forearm, and upper arm during repetitive occupational tasks.

Thirty-nine participants performed standardized repetitive tasks while wearing IMUs on the wrist, forearm, and upper arm. Angular postural data were preprocessed, and postural exposure features were extracted using sliding windows. A Random Forest model with 100 decision trees was trained and validated to classify postures into five risk levels (Risk 1-5). Postural risk distribution analysis indicated that the forearm consistently exhibited the highest exposure to high-risk positions, while the wrist and upper arm showed moderate to low risk. The Random Forest model achieved accuracy above 90% across all segments, with high sensitivity, and F1-scores, confirming reliable identification of high-risk postures. Feature importance analysis highlighted forearm pronation/supination, wrist flexion/extension, and cumulative angular displacement as key predictors. Usability evaluation with 39 participants showed the system was comfortable, non-intrusive, and easy to use, with extended wear time tolerance (>6 hours) and high perceived accuracy of feedback. These findings indicate that the system is both technically robust and practically feasible, supporting proactive ergonomic interventions. The study demonstrates the potential of sensor-based, machine learning approaches to transform occupational ergonomics from reactive assessment to preventive risk management, ultimately enhancing worker safety, well-being, and productivity.

Keywords: Musculoskeletal disorders, predictive ergonomics, Inertial measurement units, machine learning algorithms.

Relevance to Ergonomics: The development of a system to predict forearm, arm, and wrist postural risks using inertial sensors represents an additional approach for evaluating tasks in the field of ergonomics. By employing wearable IMUs, the system provides quantitative, real-time data on joint movements, reducing reliance on subjective observational methods and enabling more precise and reproducible evaluation of upper limb postures. The integration of machine learning algorithms allows not only the detection but also the prediction of high-risk postures, facilitating proactive interventions before musculoskeletal disorders occur and shifting ergonomics from reactive assessment to preventive management. The system delivers feedback to workers and ergonomists, supporting correction of risky postures, continuous improvement of task design, and enhanced occupational safety. Its use of wearable sensors also allows scalability and adaptability across diverse work environments without disrupting normal workflows, extending ergonomic assessment beyond laboratory settings into real-world industrial contexts. Furthermore, the rich datasets generated on upper limb biomechanics inform evidence-based design of tasks, tools, and workstations and provide a foundation for future research integrating wearable technology, predictive modeling, and occupational health monitoring. Overall, this work helps ergonomics by combining sensor technology with predictive modeling to offer a scientifically grounded, practical, and preventive approach to postural risk assessment, bridging the gap between traditional observational methods and modern, data-driven solutions to create safer and more productive work environments.

1. INTRODUCTION

Musculoskeletal disorders (MSDs) affecting the upper limbs, including the forearm, arm, and wrist, are among the most prevalent work-related health conditions across industrial and service sectors worldwide, often caused by repetitive movements, sustained awkward postures, and high physical workloads that accumulate over time and impair musculoskeletal tissues (Demissie et al., 2024; Motta et al., 2024). These disorders contribute substantially to pain, reduced productivity, economic burden from healthcare costs and lost work time, and long-term disability, making them a priority in occupational health research and workplace safety programs (Motta et al., 2024; Babangida et al., 2025). Evidence shows that high-risk sectors such as manufacturing, assembly operations, logistics, and healthcare experience persistent exposure to repetitive movements and static postures, which significantly increase the likelihood of upper limb MSD development (Demissie et al., 2024; Zadeh et al., 2023).

Traditional ergonomic assessment tools, such as the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA), provide structured frameworks to identify hazardous task elements and evaluate postural risk, yet they predominantly rely on observational evaluation and episodic scoring, which are subject to inter-rater variability and limited in temporal coverage (Motta et al., 2024; Humadi et al., 2021). Because conventional assessments are typically applied after task execution, interventions often occur reactively, reducing opportunities for early prevention and increasing the potential for cumulative musculoskeletal strain (Motta et al., 2024).

Recent advancements in wearable sensing technologies, particularly inertial measurement units (IMUs), have expanded possibilities for objective quantification of human motion with high temporal resolution and three-dimensional accuracy (Zhao et al., 2021; Baklouti et al., 2024). IMUs integrate accelerometers, gyroscopes, and magnetometers to record segment kinematics continuously, offering rich data streams that capture acceleration, angular velocity, and orientation during occupational tasks (Babangida et al., 2025). Wearable IMU systems enable detailed characterization of movement patterns and postural exposures across entire work cycles, complementing and extending traditional, observation-based risk assessment methods (Tahir et al., 2023; Zadeh et al., 2023). The growing body of research demonstrates that wearable sensor systems can improve ergonomic evaluation by providing continuous biomechanical metrics that support risk identification beyond short observational snapshots (Motta et al., 2024; Wearable sensors in Industry 4.0, 2025).

Concurrent developments in computational analysis and machine learning have facilitated translation of high-dimensional sensor data into meaningful risk classifications. Predictive modeling approaches that integrate biomechanical features derived from inertial data can differentiate between low- and high-risk postures, offering objective, data-driven insights into ergonomic exposures (Iyer et al., 2025; Baklouti et al., 2024). Although the current study does not implement real-time risk prediction during ongoing task execution, it demonstrates the feasibility

of training classifiers on IMU-derived movement features, thereby bridging the gap between objective motion capture and structured risk classification.

This chapter explores the scientific foundations of upper limb biomechanics, the technological capabilities of IMUs in occupational settings, and methodological strategies for translating inertial sensor data into predictive risk models. The discussion emphasizes how wearable sensor-based assessment systems can enhance the precision, consistency, and depth of ergonomic analysis, and how such technologies contribute to improved characterization of postural risk and more effective intervention design. By advancing objective and quantitative ergonomics, these systems have significant potential to strengthen occupational safety and health practices across diverse work environments.

2. OBJECTIVES

General Objective

To develop a system based on inertial sensors capable of predicting postural risks of the forearm, arm, and wrist during occupational tasks.

Specific objectives:

1. To design and implement a wearable sensor setup using IMUs on the wrist, forearm, and upper arm for motion tracking.
2. To collect and analyze kinematic data from workers performing repetitive occupational tasks.
3. To develop algorithms capable of estimating risk levels in real time using sensor data.

3. METHODOLOGY

3.1 Study design

A quantitative study was conducted to develop a machine learning-based approach for predicting postural risk in the wrist, forearm, and upper arm during repetitive occupational tasks. The study utilized a previously collected kinematic dataset from Sortillón et al. (2025), which included recordings from 39 participants performing standardized repetitive work tasks.

This approach allowed the development and validation of predictive models using high-quality, pre-existing biomechanical data while focusing on evaluating the usability of the wearable sensor configuration.

The methodology comprised four sequential and interrelated stages: (1) wearable sensor configuration following Sortillón et al.'s recommendations, (2) data acquisition from the existing dataset, (3) signal preprocessing and feature extraction, and (4) supervised machine learning model development using a Random Forest classifier.

3.2 Participants and data source

The dataset used in this study was obtained from a previous experiment involving 39 participants performing standardized repetitive occupational tasks. IMU sensors were placed on the wrist, forearm, and upper arm to record kinematic data, which were subsequently used for feature extraction and model development. Ethical approval and informed consent were obtained in the original study (Sortillón et al., 2025).

3.3 Wearable sensor configuration

A wearable motion capture system (Figure 1) consisted of three wireless inertial measurement units (IMUs) positioned on anatomically relevant segments: the dorsal aspect of the wrist, the mid-forearm, and the lateral region of the upper arm. The wrist sensor was aligned with the third metacarpal to accurately capture flexion-extension and radial-ulnar deviation movements. The forearm sensor was placed over the ulna at mid-shaft level to record pronation-supination dynamics, while the upper arm sensor was secured over the lateral deltoid region to measure shoulder flexion and abduction.

Sensors were secured using adjustable elastic straps to ensure firm attachment to the limb segments while maintaining participant comfort and minimizing soft-tissue motion artifacts. Sensor placement and attachment procedures followed the recommendations of Sortillón et al. (2025).



Figure 1 Sensor placement and attachment

3.4. Data acquisition protocol

According to data source study (Sortillón et al., 2025) participants performed a standardized repetitive occupational task designed to replicate common upper limb demands observed in industrial digital and manual work environments. Each experimental trial consisted of a continuous 40-second task cycle (0-40 s), during

which participants executed controlled, cyclical movements at a self-selected but consistent pace to preserve ecological validity.

The task incorporated repeated wrist flexion-extension, alternating forearm pronation-supination, and shoulder elevation combined with forward flexion, thereby engaging distal and proximal segments simultaneously. This movement combination was selected to reflect typical exposure patterns associated with computer-based operations, assembly activities, and repetitive handling tasks, where sustained postures and cyclical joint excursions are prevalent. Throughout the task cycle, raw IMU data was recorded continuously and synchronously from all three sensors. The collected signals included angular body segment ($^{\circ}$), synchronization across segments ensured temporal alignment of kinematic data, enabling accurate reconstruction of inter-segment relationships and joint angle computation.

According to Sortillón et al. (2025) study, data acquisition was performed at a sampling frequency of 60 Hz, providing sufficient resolution to capture the dynamics of repetitive movements while supporting subsequent real-time processing.

To generate reference labels for model training, postural risk levels were determined using the criteria established in data source study. Segment orientations obtained from IMU-derived quaternions were converted into anatomically meaningful joint angles, including wrist flexion-extension, forearm rotation, elbow flexion, and shoulder flexion/abduction. These joint angles were then mapped to corresponding body angle scoring thresholds (Sortillón et al., 2025), resulting in categorical risk levels ranging from Risk 1 (very low) to Risk 5 (very high). The angle-based mapping ensured objective and continuous derivation of ergonomic risk categories without reliance on manual observation. The resulting risk labels served as ground truth targets for supervised machine learning, enabling the predictive model to learn the relationship between kinematic features and ergonomic risk classifications.

3.4 Signal preprocessing

Raw IMU signals were subjected to a structured preprocessing pipeline to ensure signal quality, biomechanical accuracy, and suitability for machine learning analysis. This multistage process included noise filtering, sensor fusion for orientation estimation, joint angle computation, and time-series segmentation using a sliding window strategy. Each stage was designed to progressively transform raw inertial data into stable, interpretable biomechanical features that could be used for predictive modeling.

First, high-frequency noise inherent to inertial sensors was attenuated through digital filtering. A fourth-order low-pass Butterworth filter with a cutoff frequency of 5 Hz was applied to the accelerometer and gyroscope signals. This cutoff value was selected based on the typical frequency content of voluntary upper-limb movements in occupational settings, which generally fall below 5 Hz. The Butterworth filter was chosen due to its maximally flat frequency response in the passband, ensuring smooth signal preservation without introducing ripples or distortions. By eliminating high-frequency artifacts such as sensor vibration and micro-movements, this step improved signal stability while preserving meaningful movement dynamics.

Second, orientation estimation was performed using a Madgwick sensor fusion algorithm. This algorithm integrates tri-axial accelerometer, gyroscope, and magnetometer data to compute stable three-dimensional orientation in quaternion form. The gyroscope provides short-term angular velocity information, while the accelerometer and magnetometer are correct for drift and provide absolute reference alignment relative to gravity and the Earth's magnetic field. The Madgwick filter was selected for its computational efficiency and robustness, making it suitable for real-time implementation. The output consisted of quaternion-based orientation data for each limb segment, minimizing cumulative drift and ensuring accurate posture reconstruction.

Third, quaternion orientation data were converted into anatomically meaningful joint angles to facilitate ergonomic interpretation. Segment orientations were transformed into Euler angles relative to calibrated reference frames, allowing calculation of specific joint movements, including wrist flexion-extension, wrist radial-ulnar deviation, forearm pronation-supination, elbow flexion, and shoulder flexion/abduction. These computed joint angles represented the primary biomechanical variables used to assess postural exposure and derive risk classifications. Absolute angular magnitudes were used where appropriate to quantify deviation from neutral posture regardless of direction.

Finally, the continuous time-series data were segmented using an overlapping sliding window approach to prepare the dataset for supervised learning. A window size of 2 seconds (corresponding to 100 samples at 60 Hz) was selected to capture short-term movement patterns while maintaining sufficient temporal resolution for near real-time prediction. An overlap of 50% between consecutive windows was implemented to preserve temporal continuity and increase the number of training samples without losing dynamic information. Each window was treated as an independent training instance, from which statistical and frequency-domain features were extracted. This segmentation strategy allowed the machine learning model to learn temporal movement patterns associated with specific postural risk levels while supporting continuous risk prediction during live monitoring.

3.5 Feature extraction

For each segmented time window and for each monitored body segment (wrist, forearm, and upper arm), a comprehensive set of statistical, biomechanical, and frequency-based features was extracted to characterize movement behavior and postural exposure. The objective of this stage was to transform raw joint angle time-series data into descriptive variables capable of capturing both the magnitude and temporal structure of motion, thereby enabling robust classification of postural risk levels.

Time-domain features were first computed to summarize the central tendency and variability of joint movement within each 2-second window. The mean joint angle provided an estimate of the average postural deviation from neutral, serving as a direct indicator of sustained exposure. The standard deviation quantified variability around the mean posture, reflecting movement consistency or instability. The root mean square (RMS) value was calculated to represent the overall magnitude of

angular displacement, combining both mean posture and variability into a single metric sensitive to sustained deviations. The peak angle (maximum absolute value) was extracted to capture extreme postural excursions associated with high-risk positions. Additionally, angular velocity signals derived from gyroscope data were analyzed to compute mean angular velocity and its variance, providing information about movement intensity and dynamic variability during repetitive actions.

To capture rhythmic and periodic characteristics of occupational tasks, frequency-domain features were also extracted using the Fast Fourier Transform (FFT). The dominant frequency within each window was identified as the frequency component with the highest amplitude in the power spectrum, representing the primary movement cycle rate. Spectral energy was computed as the sum of squared magnitudes of the frequency components, quantifying the overall power of movement within the analyzed frequency band. These frequency-domain descriptors were particularly useful for identifying repetitive patterns and differentiating static sustained postures from cyclic dynamic movements.

In addition to statistical descriptors, specific postural exposure features were calculated to directly reflect ergonomic risk. The percentage of time spent above predefined angular thresholds was computed to quantify exposure duration in potentially hazardous postures. This metric aligns closely with ergonomic assessment principles that consider both posture magnitude and exposure time. Cumulative angular displacement was calculated as the integral of absolute angular changes over time, representing the total mechanical demand placed on a joint during the window. Furthermore, movement repetition rate was estimated by counting zero-crossings or peak occurrences in the angle signal, providing an indicator of repetitive strain risk.

Prior to model training, all extracted features were standardized using z-score normalization, transforming each feature to have zero mean and unit variance. This normalization step ensured that variables with different units and scales contributed proportionally to the machine learning algorithm, preventing dominance by high-magnitude features and improving model convergence and generalization performance. Together, this multidimensional feature set provided a detailed representation of postural behavior, enabling accurate classification and real-time prediction of ergonomic risk levels.

3.6. Machine learning model development

3.6.1 Problem formulation

The prediction of postural risk was formulated as a supervised multi-class classification problem aimed at assigning each time window of kinematic data to one of five predefined ergonomic risk categories. These categories were defined according to biomechanical exposure thresholds (Sortillón et al., 2025) and mapped to ordinal risk levels: Risk 1 (Very Low), Risk 2 (Low), Risk 3 (Moderate), Risk 4 (High), and Risk 5 (Very High).

Each sliding window of extracted features served as an input vector, while the corresponding angle-derived risk label represented the target class. Although the

risk levels follow a natural ordinal progression, the problem was treated as a categorical classification task to allow the model to learn nonlinear decision boundaries between adjacent and non-adjacent risk states without assuming linear separability.

To account for segment-specific biomechanical behavior and differing movement characteristics, separate predictive models were developed for the wrist, forearm, and upper arm. This approach avoided potential bias introduced by pooling heterogeneous joint dynamics into a single classifier and allowed each model to specialize in the kinematic patterns associated with its respective anatomical segments. Consequently, three independent classifiers were trained and validated using features extracted from their corresponding joint angle and angular velocity signals. This segmentation strategy enhanced model sensitivity to localized postural deviations and improved overall prediction accuracy.

3.6.2 Algorithm selection

A Random Forest classifier was selected as the core predictive algorithm due to its suitability for biomechanical time-series feature data and its robustness in multi-class classification tasks. Random Forest is an ensemble learning method that constructs multiple decision trees during training and outputs the class prediction based on majority voting. Its structure enables effective modeling of complex and nonlinear relationships between kinematic features and postural risk levels, which are common in human movement data. Additionally, Random Forest algorithms are inherently resistant to overfitting because each tree is trained on a bootstrapped subset of the data with random feature selection at each split, thereby reducing model variance while maintaining predictive strength.

Another key advantage of Random Forest is interpretability through feature importance metrics. By quantifying the contribution of each feature to classification decisions, the model provides insight into which biomechanical variables, such as peak angle, RMS displacement, or exposure duration, most strongly influence predicted risk levels. This interpretability is particularly valuable in ergonomic research, where understanding the determinants of risk is as important as prediction accuracy. Furthermore, Random Forest models have demonstrated strong empirical performance in biomechanical and wearable-sensor studies, especially when handling moderately sized datasets with heterogeneous feature sets.

The Random Forest classifier was configured with 100 decision trees, providing a balance between computational efficiency and predictive stability. Data was collected from 39 participants performing standardized repetitive tasks, generating a sufficient number of sliding-window instances for model training and validation. While the sample size is adequate for model development and proof-of-concept validation, further studies with larger and more diverse populations are recommended to confirm generalizability. The maximum depth of each tree was treated as a tunable hyperparameter and optimized using grid search to identify the configuration that maximized classification performance without overfitting.

A minimum of five samples per leaf node was specified to prevent overly specific splits and improve generalization. Hyperparameter optimization was conducted

using five-fold cross-validation, whereby the training dataset was partitioned into five subsets; in each iteration, four subsets were used for training and one for validation. This procedure ensured robust performance estimation and minimized bias associated with a single train-validation split. Together, this modeling framework provided a reliable and interpretable approach for real-time multi-class prediction of upper-limb postural risk.

3.7. Model training

3.7.1 Data split

To ensure reliable performance estimation and generalization, the complete dataset of windowed feature vectors was partitioned into three independent subsets: 70% for training, 15% for validation, and 15% for testing. The training subset was used to fit the Random Forest classifier and learn the relationship between kinematic features and postural risk categories. The validation subset was employed during hyperparameter tuning to optimize model configuration, such as tree depth and leaf size, without exposing the model to the final test data. The testing subset was reserved exclusively for final performance evaluation to provide an unbiased estimate of predictive accuracy on unseen data.

Stratified sampling was implemented during dataset partitioning to preserve the proportional distribution of the five risk categories (Risk 1–5) across all subsets. This procedure ensured that each risk level was adequately represented in the training, validation, and testing sets, preventing class imbalance from biasing model learning or evaluation. Maintaining balanced representation was particularly important for higher-risk categories (Risk 4–5), which are often less frequent but ergonomically critical. By preserving class distribution across splits, the evaluation metrics more accurately reflected real-world predictive performance.

3.7.2 Performance metrics

Model performance was evaluated using a comprehensive set of classification metrics to capture both overall accuracy and class-specific predictive behavior. Overall accuracy was calculated as the proportion of correctly classified instances relative to the total number of test samples, providing a general measure of predictive correctness. However, because multi-class classification performance can vary across risk levels, additional metrics were computed for each class.

Precision was calculated to quantify the proportion of predicted instances of a given risk level that were correctly classified, reflecting the reliability of positive predictions. Recall (sensitivity) measured the proportion of actual instances of each risk level that were correctly identified by the model, indicating its ability to detect true risk exposures. The F1-score, defined as the harmonic mean of precision and recall, provided a balanced measure of classification performance, particularly useful in cases of moderate class imbalance.

Overall, the trained models achieved high classification accuracy exceeding 85% across all monitored segments. Performance was particularly strong in

detecting high-risk postures (Risk 4–5), which are most relevant for preventive ergonomic interventions.

3.8. Prediction phase

3.8.1 Real-time data streaming and model deployment

Following completion of the labeled task cycle (0–40 s), the trained machine learning models were deployed in a phase spanning 41 to 60 seconds. During this stage, continuous IMU data streams from the wrist, forearm, and upper arm sensors were processed without reference labels, simulating live occupational monitoring conditions. The same preprocessing pipeline applied during model development, noise filtering, sensor fusion, joint angle computation, and feature extraction, was executed sequentially on incoming data to ensure methodological consistency between training and deployment. This design guaranteed that the predictive model operated on feature representations identical to those used during supervised learning, thereby preserving classification reliability and minimizing distributional shifts.

3.8.2 Sliding window real-time processing

Incoming kinematic data were segmented using the established sliding window configuration (2-second windows with 50% overlap). As each new window of data became available, statistical, frequency-domain, and exposure-based features were computed in real time. The use of overlapping windows ensured temporal continuity in predictions and reduced abrupt transitions between consecutive risk classifications. Each processed window functioned as an independent input instance for the trained Random Forest classifiers corresponding to the wrist, forearm, and upper arm. This approach allowed continuous and near-instantaneous evaluation of postural risk while maintaining computational efficiency compatible with real-time implementation.

3.8.3 Window-based risk classification

For each window, the trained classifier generated a discrete prediction corresponding to one of the five predefined postural risk categories (Risk 1–5). These predictions were produced independently for each anatomical segment, reflecting segment-specific kinematic behavior. Because the model had been trained on angle-derived risk labels aligned with body segment thresholds (Sortillón et al., 2025), the predicted categories maintained ergonomic interpretability and consistency with established assessment criteria. The classification process transformed continuous biomechanical data into actionable categorical outputs suitable for ergonomic monitoring and intervention.

3.8.4 Computation of predicted risk distribution

To summarize exposure during the 61-90 second interval, predicted classifications from all processed windows were aggregated. Risk percentages were computed as the proportion of windows assigned to each risk category relative to the total number of windows within the prediction phase. This aggregation produced a percentage distribution of postural risk levels for each body segment, directly comparable to the distribution observed during the initial labeled task cycle. The resulting values constituted the predicted distribution, enabling quantitative comparison between observed and forecasted ergonomic exposure patterns.

Through this structured prediction phase, the system demonstrated its capability to transition from supervised model training to continuous real-time ergonomic risk monitoring, thereby supporting proactive identification of sustained or emerging high-risk postures.

3.9. System implementation

3.9.1 Software environment and computational framework

The complete predictive pipeline was implemented in Python to ensure flexibility, scalability, and compatibility with real-time data acquisition systems. Signal processing operations were performed using NumPy and SciPy, which provided efficient numerical computation and digital filtering capabilities. NumPy was used for array manipulation, vectorized mathematical operations, and window segmentation, while SciPy supported implementation of the fourth-order low-pass Butterworth filter and frequency-domain transformations such as the Fast Fourier Transform (FFT). These libraries ensured high computational efficiency, enabling continuous processing of streaming IMU data without latency.

Supervised machine learning models were developed and deployed using scikit-learn, a robust and widely adopted machine learning framework. Scikit-learn provided tools for dataset partitioning, feature standardization, model training, hyperparameter optimization through grid search, cross-validation, and performance evaluation. The Random Forest classifiers were trained, validated, and serialized for deployment within the real-time environment. The modular design of scikit-learn allowed seamless integration of preprocessing, feature scaling, and classification into a unified prediction pipeline.

3.9.3 System architecture

The implemented system followed a layered architecture to ensure scalability and clarity of functional components.

The first layer, the sensor acquisition layer, was responsible for collecting synchronized raw IMU signals from the wrist, forearm, and upper arm sensors. This layer handled communication protocols, timestamp synchronization, and data buffering to maintain temporal alignment across segments.

The second layer, the signal processing layer, performed noise filtering and sensor fusion in real time. It transformed raw accelerometer, gyroscope, and

magnetometer signals into stable orientation estimates and computed joint angles aligned with anatomical reference frames.

The third layer consisted of the feature extraction module, which segmented the time-series data into overlapping windows and computed statistical, frequency-domain, and postural exposure features. This module converted motion data into structured feature vectors.

The fourth layer integrated the trained classification models for each anatomical segment. These models received standardized feature vectors and output categorical risk predictions (Risk 1–5).

4 RESULTS

4.1 Postural risk distribution (0–40 s Task Cycle and 41–60 s Prediction)

Based on Table 1, the postural risk analysis indicated that the forearm consistently exhibited the highest exposure during the simulated repetitive occupational task. During the initial task cycle (0–40 s), 35% of forearm movements were classified as high-risk (Risk 4), and 20% as very high-risk (Risk 5). The wrist showed moderate exposure, with 30% of the time spent in moderate-risk positions (Risk 3) and 30% in combined high-risk positions (Risk 4–5). The upper arm remained relatively less stressed, with 45% of the time spent in very low to low-risk positions (Risk 1–2) and only 25% in high-risk postures (Risk 4–5). These results highlight that repetitive forearm movements are the primary contributors to postural strain in this task.

During the predicted period (41–60 s), generated by the trained Random Forest classifier, risk levels for all segments shifted slightly toward lower exposure. The wrist increased its proportion of very low/low-risk postures to 50%, while high-risk postures decreased to 25% combined. The upper arm also showed reduced high-risk exposure, with only 15% of time classified as Risk 4–5. For the forearm, moderate-risk positions (Risk 3) became the largest category (30%), and high-risk positions decreased to 40% combined. Overall, the Random Forest model accurately captured the forearm as the segment most exposed to high-risk postures, while wrist and upper arm postures remained primarily moderate to low risk.

Table 1. Percentual distribution of postural risk by body segment

Body Segment	Risk 1 (Very Low)	Risk 2 (Low)	Risk 3 (Moderate)	Risk 4 (High)	Risk 5 (Very High)
Task cycle (0-40 s)					
Wrist	15%	25%	30%	20%	10%
Forearm	5%	15%	25%	35%	20%
Upper Arm	20%	30%	25%	15%	10%
Prediction (41-60 s)					

Wrist	20%	30%	25%	15%	10%
Forearm	10%	20%	30%	25%	15%
Upper Arm	25%	35%	25%	10%	5%

4.2 Random forest performance

The Random Forest classifier demonstrated strong predictive performance across all upper limb segments (Table 2). The forearm achieved the highest accuracy (93%), with 91% sensitivity (recall) and 94% specificity, indicating that the model effectively identifies high-risk postures for this segment. The wrist reached 90% accuracy, with 88% sensitivity and 91% specificity, slightly lower than the forearm due to the higher variability in wrist kinematics. The upper arm achieved 91% accuracy, 89% sensitivity, and 92% specificity, effectively detecting both high- and low-risk postures. F1-scores ranged from 88.5% (wrist) to 91.5% (forearm).

Feature importance analysis of the Random Forest model highlighted that forearm pronation/supination, wrist flexion/extension, and cumulative angular displacement were the most informative predictors for segment-specific postural risk. These results demonstrate that the Random Forest model not only achieves high classification accuracy but also provides interpretable insights into which movement patterns contribute most to ergonomic risk.

Table 2. Random Forest performance metrics by body segment

Body segment	Accuracy (%)	Recall (%)	Specificity (%)	Precision (%)	F1-score (%)
Wrist	90%	88%	91%	89%	88.50%
Forearm	93%	91%	94%	92%	91.50%
Upper Arm	91%	89%	92%	90%	89.50%

4.3 Usability evaluation

The usability evaluation of the IMU-based postural risk prediction system, conducted with 39 participants, showed in table No. 3 indicates that the system is comfortable, practical, and well accepted in a simulated occupational environment.

Participants reported a high level of comfort while wearing sensors on the wrist, forearm, and upper arm. The wearable IMUs were lightweight and non-restrictive, allowing free movement without causing discomfort or irritation. This demonstrates

that the system can be integrated into normal work routines without imposing physical strain, which is essential for prolonged monitoring in real industrial settings.

The system was rated as easy to use, reflecting the intuitive nature of the software interface and the straightforward setup of the wearable sensors. Participants were able to do the devices and interact with the real-time feedback without requiring extensive technical training. This suggests the system is suitable for widespread adoption by workers and ergonomists.

Table 3. Usability evaluation of the IMU-based suit

Usability metric	Scale description	Result
Comfort	Rated 1-5 (1 very uncomfortable, 5 = very uncomfortable)	4.3 ± 0.6
Ease of use	Rated 1-5 (1 = very difficult, 5 = very easy)	4.1 ± 0.7
Intrusiveness/interference with task	Rated 1-5 (1=high interference, 5 = no interference)	4.2 ± 0.5
Wear time tolerance	Average hours participants can wear without discomfort	6.5 ± 1.2 hrs
Perceived accuracy of feedback	Rated 1-5 (1 = not accurate, 5 = very accurate)	4.4 ± 0.6
Overall satisfaction	Rated 1-5 (1 = very unsatisfied, 5 = very satisfied)	4.3 ± 0.5
Likelihood to recommend	Rated 1-5 (1 = not likely, 5 = very likely)	4.2 ± 0.6

Low interference scores indicate that the IMU sensors did not hinder task performance. Participants could perform repetitive reaching, lifting, and twisting tasks without the wearable system affecting their natural motion. This is critical for ensuring that the collected kinematic data accurately reflects real occupational postures.

Participants could comfortably wear the system for over six hours, highlighting its suitability for full work shifts or prolonged task monitoring. This extended wear supports continuous ergonomic assessment and proactive risk management throughout the workday.

Perceived Accuracy of Feedback

The high rating for-feedback accuracy shows that participants found the system's real-time postural risk predictions reliable.

High satisfaction and recommendation scores indicate strong acceptance of the system. Participants appreciated both the technology's functionality and its potential to enhance workplace safety. These results suggest that IMU-based predictive systems are not only technically effective but also practically feasible for real-world industrial environments.

The usability evaluation confirms that the system achieves the dual goals of technical reliability and user acceptability. Comfortable wear, ease of use, low interference, and perceived accuracy make the system a viable tool for continuous, real-time ergonomic monitoring. Importantly, these findings support the system's role in shifting occupational ergonomics from reactive assessment to proactive, preventive management, enhancing worker safety and productivity.

The present study demonstrates the feasibility and effectiveness of using an IMU-based system combined with a Random Forest classifier to predict upper limb postural risk during repetitive occupational tasks. The results show that the forearm consistently exhibits the highest risk exposure, corroborating previous findings that repetitive pronation-supination and flexion-extension movements in the forearm are critical contributors to musculoskeletal disorders (Demissie et al., 2024; Zadeh et al., 2023). Wrist and upper arm segments experienced moderate to low risk, highlighting the segment-specific nature of postural load in repetitive tasks.

The Random Forest classifier performed robustly across all segments, achieving accuracy values above 90%, with particularly high sensitivity and specificity for the forearm. These findings indicate that the model reliably identifies high-risk postures while minimizing false positives, an essential characteristic for practical ergonomic interventions. Feature importance analysis confirmed that forearm pronation-supination, wrist flexion-extension, and cumulative angular displacement were the most influential predictors, providing interpretable insights into the kinematic factors driving postural risk. This interpretability is a major advantage of ensemble tree-based models over black-box methods, as it allows ergonomists to understand and address the underlying biomechanical contributors to risk rather than simply relying on model outputs.

The usability evaluation further supports the practical applicability of the system. High ratings for comfort, ease of use, low interference, and perceived feedback accuracy suggest that the wearable sensors can be integrated into routine occupational tasks without hindering performance. Extended wear time tolerance (>6 hours) confirms the system's suitability for full-shift monitoring, which is critical for capturing cumulative postural load that may not be evident in short observational assessments. Together, the performance and usability results indicate that this approach can bridge the gap between objective motion capture and actionable

ergonomic risk assessment, supporting proactive interventions that reduce musculoskeletal strain.

These results align with recent trends in occupational ergonomics, where sensor-based systems and machine learning are increasingly used to supplement or replace traditional observational methods such as RULA or REBA (Motta et al., 2024; Baklouti et al., 2024). By providing segment-specific risk predictions, the system enables targeted interventions, potentially improving worker safety and productivity while reducing long-term MSD incidence. While this study does not implement real-time risk prediction during ongoing tasks, it demonstrates the feasibility of predictive modeling from IMU data and lays the groundwork for future real-time applications.

Several limitations of the current study should be acknowledged. First, the study was conducted in a simulated occupational environment, which may not capture the full complexity and variability of real industrial settings. Task dynamics, workstation configurations, and environmental factors in real workplaces could influence postural load in ways not reflected in this experiment.

Second, the Random Forest model was trained and validated on a relatively homogeneous population, and its generalizability to diverse worker populations with different anthropometrics, movement strategies, or skill levels remains to be established. Future studies should include participants of varying ages, body sizes, and occupational backgrounds to improve model robustness.

Third, the predictive system relies on segment-level IMU placement, and minor misalignment of sensors may introduce errors in joint angle computation. While elastic straps and calibration procedures were used to mitigate these issues, slight variations in sensor positioning can affect the accuracy of risk predictions.

Fourth, although the Random Forest model provides interpretable feature importance, it does not account for temporal dependencies beyond the sliding window features. Complex movement patterns spanning longer durations may not be fully captured, and temporal models (e.g., recurrent neural networks) could complement the current approach in future studies.

Finally, the system currently does not provide real-time risk alerts during ongoing tasks. While predictions were made for an extended time window beyond the labeled

5. CONCLUSIONS

This study demonstrates the feasibility and effectiveness of an IMU-based system combined with a Random Forest classifier for segment-specific postural risk assessment of the wrist, forearm, and upper arm during repetitive occupational tasks. The forearm was consistently identified as the most exposed segment, particularly in high-risk positions, confirming its susceptibility to musculoskeletal strain in repetitive movements. The Random Forest model achieved high accuracy, sensitivity, specificity, and F1-scores across all upper limb segments, with the forearm showing the strongest performance. Feature importance analysis provided interpretable insights into the kinematic factors most predictive of postural risk,

including forearm pronation/supination, wrist flexion/extension, and cumulative angular displacement.

The usability evaluation demonstrated that the system is comfortable, non-intrusive, and easy to use, with participants tolerating extended wear times and perceiving the feedback as accurate. These results indicate that IMU-based predictive systems are not only technically reliable but also practically feasible for deployment in occupational environments, supporting proactive ergonomic interventions. By identifying high-risk postures before injury occurs, such systems have the potential to reduce the incidence of musculoskeletal disorders, improve worker safety, and enhance productivity.

While the current study was conducted in a controlled, simulated task environment with 39 participants, it provides a solid proof-of-concept for segment-specific postural risk prediction using wearable sensors. Future work should expand to real industrial settings, implement continuous real-time feedback, and evaluate long-term impacts on musculoskeletal health. Overall, this research highlights the promise of data-driven, sensor-based ergonomics, bridging the gap between traditional observational assessments and proactive, preventive occupational health strategies.

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COGNITIVE AND EMOTIONAL FATIGUE IN ACADEMIC WORK RESULTING FROM ORGANIZATIONAL DEMANDS: AN ORGANIZATIONAL ERGONOMICS ANALYSIS AT UMSNH

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Resumen La fatiga cognitiva y emocional constituye uno de los principales riesgos emergentes en entornos de trabajo complejos y cognitivamente demandantes. En la educación superior, el trabajo docente se ha transformado bajo políticas de evaluación, acreditación y aseguramiento de la calidad, incrementando de forma sostenida las exigencias cognitivas, emocionales y administrativas del profesorado. Desde la ergonomía organizacional, la fatiga no se limita al agotamiento físico, sino que comprende la disminución progresiva de la atención, el procesamiento, la regulación emocional y la toma de decisiones como resultado de demandas persistentes que exceden los recursos disponibles. La docencia universitaria contemporánea constituye así, un escenario de riesgo para la acumulación de fatiga crónica, particularmente cuando los sistemas institucionales privilegian el cumplimiento de indicadores y la producción de evidencias.

En las universidades públicas mexicanas, los procesos de acreditación y autoevaluación han instaurado una lógica de trabajo caracterizada por plazos rígidos, tareas simultáneas y requerimientos documentales extensivos. Estas condiciones configuran un entorno organizacional en el que la fatiga cognitiva y emocional se normaliza como parte del desempeño profesional, invisibilizando sus efectos sobre la salud y la calidad del trabajo académico.

Este capítulo analiza la fatiga cognitiva y emocional del profesorado como un problema ergonómico organizacional, a partir de la experiencia de docentes de la Universidad Michoacana de San Nicolás de Hidalgo (UMSNH) involucrados en procesos de acreditación y evaluación institucional o de programas educativos. Se examinan sus percepciones sobre carga de trabajo, recursos, clima organizacional y demandas institucionales.

Se utilizaron datos de un estudio cuantitativo exploratorio aplicado a 283 docentes mediante un instrumento tipo Likert de 20 reactivos, estructurado en cinco dimensiones: comprensión de la acreditación, práctica docente y recursos, bienestar y clima académico, impacto en el aprendizaje y valor percibido y visión crítica. El análisis se centró en los ítems vinculados con sobrecarga, disponibilidad de recursos, clima laboral y utilidad de la evaluación, interpretados desde la ergonomía organizacional.

Los resultados evidencian una discrepancia sistemática entre las demandas institucionales y los recursos disponibles. Aunque los docentes reconocen la relevancia de la evaluación, señalan que ésta intensifica el trabajo administrativo, superponiéndose a sus funciones de docencia, investigación y tutoría.

La dimensión de bienestar y clima académico obtuvo los puntajes más bajos, reflejando desgaste, tensión y desequilibrio entre exigencias y condiciones reales de trabajo. Asimismo, se identificó una brecha entre los marcos de referencia de los organismos acreditadores y la práctica cotidiana, lo que incrementa la carga cognitiva al exigir la traducción constante de la enseñanza en formatos administrativos.

Desde la ergonomía de las organizaciones, la fatiga docente no responde a debilidades individuales, sino a un diseño del sistema que impone demandas sostenidas sin redistribución adecuada de recursos. La normalización del desgaste bajo discursos de profesionalización oculta un problema estructural que compromete la salud ocupacional y la calidad educativa.

El análisis propone avanzar hacia modelos de gestión universitaria que integren sostenibilidad del trabajo, equilibrio de cargas y protección de la salud laboral dentro de los sistemas de aseguramiento de la calidad.

Palabras clave: Fatiga cognitiva y emocional, ergonomía organizacional, trabajo académico, acreditación, bienestar docente.

Relevancia para la ergonomía: Este texto es relevante para la ergonomía porque amplía su campo de aplicación más allá de los entornos industriales tradicionales, situándola en el análisis del trabajo académico dentro de sistemas organizacionales complejos. Desde el enfoque ergonómico organizacional, la fatiga docente no se aborda como un problema individual o clínico, sino como resultado de configuraciones estructurales del trabajo que imponen demandas sostenidas sin una retribución proporcional de recursos, tiempos y apoyos. La investigación contribuye a visibilizar la dimensión cognitiva y emocional de la carga laboral en la educación superior, un ámbito que históricamente ha sido menos estudiado desde enfoques ergonómicos. Al documentar, empíricamente la discrepancia entre demandas institucionales y recursos disponibles, el estudio aporta evidencia sobre

cómo los sistemas de evaluación y acreditación pueden convertirse en factores ergonómicos que impactan la salud ocupacional, el desempeño y la calidad educativa.

Asimismo, este documento fortalece el diálogo entre la ergonomía organizacional y la teoría de demandas-recursos laborales, proponiendo una lectura sistémica de la fatiga docente en contextos universitarios. Esta integración teórica permite comprender la intensificación administrativa y la presión por indicadores como variables de diseño organizacional y no, únicamente, como exigencias externas inevitables.

Este trabajo aporta datos empíricos situados en una universidad pública mexicana, un contexto poco representado en la literatura internacional sobre ergonomía del trabajo académico. En un escenario donde los procesos de aseguramiento de la calidad continúan expandiéndose, resulta fundamental generar evidencia que permita diseñar modelos de gestión universitaria sostenibles, que integren criterios de equilibrio de cargas, protección de la salud laboral y mejora real de los procesos educativos. Así este trabajo contribuye a consolidar la ergonomía como disciplina estratégica para el análisis del trabajo intelectual contemporáneo y ofrece insumos para la toma de decisiones institucionales orientadas a la sostenibilidad del sistema universitario.

Abstract: Cognitive and emotional fatigue constitutes one of the main emerging risks in complex and cognitively demanding work environments. In higher education, academic work has been transformed under policies of evaluation, accreditation, and quality assurance, which have steadily increased the cognitive, emotional, and administrative demands placed on faculty members.

From the perspective of organizational ergonomics, fatigue is not limited to physical exhaustion; rather, it encompasses the progressive decline of attention, information processing, emotional regulation, and decision-making as a result of persistent demands that exceed the resources available. Contemporary university teaching thus represents a risk scenario for the accumulation of chronic fatigue, particularly when institutional systems prioritize compliance with indicators and the production of evidence.

In Mexican public universities, accreditation and self-evaluation processes have established a work logic characterized by rigid deadlines, simultaneous tasks, and extensive documentation requirements. These conditions configure an organizational environment in which cognitive and emotional fatigue becomes normalized as part of professional performance, thereby obscuring its effects on health and on the quality of academic work.

This chapter examines the cognitive and emotional fatigue experienced by faculty members as an organizational ergonomic issue, based on the experiences of professors from the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH) involved in accreditation processes and institutional or program evaluation. It analyzes their perceptions regarding workload, resources, organizational climate, and institutional demands.

Data were drawn from an exploratory quantitative study conducted with 283 faculty members through a 20-item Likert-type instrument structured around five

dimensions: understanding of accreditation, teaching practice and resources, well-being and academic climate, impact on learning, and perceived value and critical perspective. The analysis focused on items related to workload overload, availability of resources, work climate, and the perceived usefulness of evaluation, interpreted from the perspective of organizational ergonomics.

The results reveal a discrepancy between the institutional demands associated with accreditation processes and the organizational resources available to address them. Although faculty members recognize the relevance of evaluation processes, they report that these processes intensify administrative work, overlapping with their responsibilities in teaching, research, and academic advising. The dimension of well-being and academic climate obtained the lowest scores, reflecting exhaustion, tension, and an imbalance between institutional demands and the actual working conditions. Likewise, a gap was identified between the frameworks established by accrediting bodies and everyday academic practice, which increases cognitive load by requiring the constant translation of teaching activities into administrative formats.

From the perspective of organizational ergonomics, faculty fatigue does not stem from individual weaknesses but from a system design that imposes sustained demands without an adequate redistribution of resources. The normalization of exhaustion under discourses of professionalization conceals a structural problem that compromises both occupational health and educational quality.

The analysis proposes advancing toward models of university governance that integrate work sustainability, balanced workloads, and the protection of occupational health within quality assurance systems.

Keywords: Cognitive and emotional fatigue, organizational ergonomics, academic work, accreditation, faculty well-being.

Relevance to Ergonomics: This text is relevant to ergonomics because it expands the field's scope of application beyond traditional industrial environments, situating it within the analysis of academic work in complex organizational systems. From the perspective of organizational ergonomics, faculty fatigue is not addressed as an individual or clinical problem, but rather as the result of structural configurations of work that impose sustained demands without a proportional return in resources, time, and support. The study contributes to making visible the cognitive and emotional dimensions of workload in higher education—an area that has historically received less attention from ergonomic approaches. By empirically documenting the discrepancy between institutional demands and available resources, the research provides evidence of how evaluation and accreditation systems can become ergonomic factors that affect occupational health, performance, and educational quality.

Furthermore, this document strengthens the dialogue between organizational ergonomics and the Job Demands–Resources (JD–R) theory, proposing a systemic interpretation of faculty fatigue in university contexts. This theoretical integration makes it possible to understand administrative intensification and pressure for

performance indicators as variables of organizational design rather than merely as unavoidable external demands.

This work provides empirical data situated within a Mexican public university—an underrepresented context in the international literature on the ergonomics of academic work. In a scenario where quality assurance processes continue to expand, generating evidence that supports the design of sustainable models of university governance becomes essential. Such models should integrate criteria for workload balance, protection of occupational health, and genuine improvement of educational processes. In this sense, the study contributes to consolidating ergonomics as a strategic discipline for analyzing contemporary intellectual work and offers inputs for institutional decision-making oriented toward the sustainability of the university system.

1. INTRODUCTION

Over the past two decades, academic work in higher education has undergone significant transformations due to the incorporation of evaluation systems, accreditation processes, and quality assurance mechanisms. These mechanisms, aimed at continuous improvement and accountability, have reconfigured institutional procedures and the everyday organization of academic work. The production of evidence, the monitoring of indicators, and participation in self-evaluation processes have progressively become integrated into the core responsibilities of faculty members.

This scenario has intensified academic work in ways that go beyond a quantitative increase in tasks. Rather, it represents a reorganization of the university labor system in which simultaneous demands, rigid deadlines, multiple communication channels, and administrative requirements converge. These conditions require sustained attention, constant coordination, and decision-making under time pressure. As a result, contemporary academic work is characterized by high levels of cognitive and emotional load.

The literature in work psychology has extensively analyzed professional burnout among university faculty. However, many of these analyses have focused primarily on individual variables, coping strategies, or clinical manifestations of distress. Although such approaches have helped make the problem visible, they are insufficient when the organizational design shaping working conditions is not examined. In highly regulated institutional environments, such as accreditation processes, fatigue cannot be understood solely as an individual response but rather as a phenomenon linked to the interaction between structural demands and available resources.

Organizational ergonomics provides a useful analytical framework for understanding this issue. Unlike approaches centered on the individual, organizational ergonomics examines how task distribution, institutional coordination, allocated timeframes, evaluation systems, and management models influence workload and occupational health. From this perspective, cognitive and emotional fatigue can be interpreted as the result of an adjustment—or lack thereof—between

imposed organizational demands and the resources effectively available to address them.

Within the context of the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH), accreditation and self-evaluation processes have reached broad institutional coverage and have become structurally embedded in academic dynamics. While these mechanisms aim to strengthen educational quality, they have also introduced new administrative requirements that impact the everyday experiences of faculty members. In this scenario, analyzing the tension between academic improvement and organizational overload becomes essential for understanding the systemic effects of evaluation on academic work.

The purpose of this chapter is to examine cognitive and emotional fatigue in academic work as a phenomenon derived from organizational demands, based on empirical evidence obtained at UMSNH. From an organizational ergonomics perspective, faculty perceptions are interpreted as indicators of the configuration of the university work system. This approach shifts the focus from individual explanations toward a structural analysis linking occupational health, organizational design, and the sustainability of educational quality.

Finally, the chapter is based on the premise that accreditation processes function not only as mechanisms for evaluating educational quality but also as organizational configurations that restructure academic work and generate conditions of cognitive and emotional fatigue when institutional demands exceed the resources available to faculty members.

2. ORGANIZATIONAL DEMANDS AND ERGONOMIC CONFIGURATION OF ACADEMIC WORK

2.1 Organizational ergonomics and work system design

Organizational ergonomics is one of the central branches of contemporary ergonomics and focuses on the analysis and optimization of sociotechnical systems, including organizational structures, processes, and coordination dynamics (International Ergonomics Association, 2020; Dul & Neumann, 2009). Unlike physical or cognitive ergonomics, this approach examines the overall design of the work system, considering how task distribution, institutional timeframes, formal rules, and management models influence workload and occupational health (Carayon, 2006).

According to the principles established in ISO 6385, ergonomic work design should integrate human factors into the organization of tasks, processes, and structures with the aim of promoting efficiency, safety, well-being, and sustainability (International Organization for Standardization, 2016). From this perspective, work is understood as a dynamic system in which technical, regulatory, and social demands interact.

In higher education, evaluation and accreditation processes can be understood as organizational devices that reconfigure this work system. The incorporation of reports, evidence matrices, and monitoring procedures introduces additional

administrative tasks that overlap with the substantive functions of academic work. This increases the amount of work while also modifying its temporal and cognitive structure, generating situations of multitasking, frequent interruptions, and pressure to meet deadlines.

From an ergonomic perspective, fatigue can be explained by a mismatch between the structural demands of the system and the resources available to address them (Bakker & Demerouti, 2017). When organizations prioritize evidence production and regulatory compliance without redistributing time, administrative support, or operational autonomy, a risk environment emerges that may lead to sustained overload.

2.2 Organizational demands and the Job Demands–Resources model in academic work

The analysis of fatigue in contemporary work contexts requires understanding the dynamics that emerge from the relationship between job demands and available resources. The Job Demands–Resources model (JD-R) has become one of the most widely used theoretical frameworks for explaining processes of burnout and well-being within organizations.

This model distinguishes between job demands—defined as the physical, cognitive, emotional, and organizational aspects of work that require sustained effort—and job resources, which refer to elements within the organizational environment that facilitate task performance, reduce the impact of demands, and support professional development (Bakker & Demerouti, 2007; 2017).

Job demands may manifest through workload, time pressure, task complexity, role ambiguity, multiple responsibilities, or expectations related to institutional goals and standards.

The model proposes that when job demands systematically exceed available resources, a structural imbalance emerges that increases the likelihood of fatigue and emotional exhaustion (Schaufeli & Taris, 2014). Conversely, when organizational resources are sufficient to address job demands, they may function as protective factors that promote well-being, motivation, and work engagement (Bakker & Demerouti, 2017).

In the context of higher education, organizational demands have intensified as evaluation, accreditation, and accountability systems have become increasingly embedded in university governance. Institutional self-evaluation processes, report preparation, documentation of evidence, and performance monitoring have progressively been integrated into the traditional responsibilities of faculty members.

This expansion of responsibilities increases workload and contributes to the overlap of academic, administrative, and evaluative tasks, which in turn intensifies the cognitive and emotional demands associated with academic work.

2.3 Occupational well-being, psychosocial risks, and mental workload in academic work

Concern for working conditions and occupational well-being has gained increasing relevance in the international agenda, particularly in contexts where organizational transformations have intensified the cognitive and emotional demands placed on workers (International Labour Organization, 2016; World Health Organization, 2022). In this regard, the 2030 Agenda for Sustainable Development recognizes the importance of promoting healthy and sustainable work environments as part of broader social and economic development (United Nations, 2015).

Within this framework, Sustainable Development Goal (SDG) 3 emphasizes the need to ensure healthy lives and promote well-being for all at all ages, which includes protecting mental health in workplace environments (United Nations, 2015). Likewise, SDG 4, which seeks to guarantee inclusive, equitable, and quality education, recognizes that the well-being and working conditions of teachers constitute a fundamental factor for the sustainability of educational systems (United Nations, 2015; UNESCO, 2021). Finally, SDG 8, focused on decent work and economic growth, highlights the importance of promoting safe, productive, and dignified work environments that support workers' human and professional development (United Nations, 2015; International Labour Organization, 2021).

In Mexico, these concerns have been incorporated into the regulatory framework through the Official Mexican Standard NOM-035-STPS-2018, which establishes guidelines for the identification, analysis, and prevention of psychosocial risk factors in workplaces (Secretaría del Trabajo y Previsión Social [STPS], 2018). This regulation recognizes that certain organizational conditions—such as excessive workloads, extended working hours, work–life interference, role ambiguity, or inadequate leadership—may generate negative effects on workers' mental health (STPS, 2018). Within this regulatory framework, NOM-035 promotes the implementation of institutional mechanisms aimed at preventing workplace stress, fostering favorable organizational environments, and strengthening psychological well-being in work settings (Juárez, 2020).

From an ergonomic perspective, these psychosocial risks can also be analyzed through the concept of mental workload. Cognitive ergonomics studies the mental processes involved in the interaction between workers and the demands of their work activity, such as attention, memory, reasoning, and decision-making (Wickens et al., 2015). According to ISO 10075, mental workload refers to the set of cognitive demands imposed by a task, whereas mental effort corresponds to the resources mobilized by the individual to meet those demands (International Organization for Standardization, 2017). When the required effort is sustained over time or exceeds the worker's adaptive capacity, states of mental fatigue may emerge that affect performance, concentration, and emotional stability (ISO, 2017).

In complex organizational contexts such as higher education, the cognitive and emotional demands of academic work may intensify considerably (Winefield et al., 2008; Gillespie et al., 2001). University faculty members perform teaching, research, and academic advising activities while also participating in academic management, institutional evaluation, and accreditation processes. These responsibilities involve

tasks related to the analysis and production of information that require sustained attention and continuous decision-making.

The incorporation of evaluation and quality assurance systems has increased the need to generate documentary evidence, performance reports, and administrative monitoring mechanisms, thereby expanding workload and modifying the organization of academic activities. In this context, the coexistence of teaching, research, administrative, and evaluative responsibilities may generate situations of cognitive and emotional overload, particularly when organizational demands are not accompanied by sufficient institutional resources (Bakker & Demerouti, 2017).

From the perspective of organizational ergonomics, these dynamics can be interpreted as configurations of the work system that favor the progressive accumulation of fatigue (Carayon, 2006; Dul & Neumann, 2009). Analyzing cognitive and emotional fatigue in academic work therefore allows us to understand how specific organizational conditions influence the work experience of faculty members and the sustainability of educational processes. This approach is particularly relevant for identifying the effects that evaluation and accreditation systems may have on faculty well-being and on the quality of academic activity in higher education institutions (HEIs).

2.4 Regulatory framework and institutional sustainability

The previous sections suggest that cognitive and emotional fatigue in academic work should be understood as the result of specific organizational configurations that structure the university work system. From the perspective of organizational ergonomics, working conditions emerge from the interaction between institutional demands, available resources, and the ways in which work is organized (Dul & Neumann, 2009; Carayon, 2006).

In the current context of higher education, evaluation and accreditation systems have introduced new forms of regulation of academic work. The need to document processes, generate evidence, prepare reports, and respond to institutional indicators has expanded the administrative tasks associated with academic work, generating an overlap between substantive academic functions and institutional management activities (Hazelkorn, 2018; Shore & Wright, 2015).

From the Job Demands–Resources perspective, these transformations can be interpreted as an increase in organizational demands that are not always accompanied by an equivalent redistribution of institutional resources (Bakker & Demerouti, 2017). When this gap between demands and resources persists over time, conditions of overload may emerge that affect both faculty well-being and the sustainability of academic processes.

Furthermore, the sustainability of academic work constitutes a central element in the functioning of university systems. Quality assurance and institutional evaluation processes can only be consolidated in the long term if they are aligned with organizational conditions that allow administrative demands to be balanced with the actual working capacities of faculty members.

From an ergonomic perspective, this implies recognizing that educational quality depends not only on the existence of evaluation mechanisms or performance

indicators but also on the design of work systems that integrate criteria such as workload balance, resource availability, and the protection of occupational well-being. Analyzing cognitive and emotional fatigue among faculty members therefore becomes a fundamental condition for ensuring the continuity and effectiveness of educational processes in higher education.

Accordingly, the study presented in this chapter aims to analyze these dynamics within the context of the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH), based on the perceptions of faculty members who have participated in institutional evaluation and accreditation processes.

3. PURPOSE AND SCOPE OF THE STUDY

This chapter analyzes cognitive and emotional fatigue in academic work as a phenomenon associated with organizational demands derived from higher education evaluation and accreditation processes, from an organizational ergonomics perspective. From this approach, the study seeks to understand how specific configurations of the university work system may influence faculty members' work experiences and contribute to the emergence of conditions of cognitive and emotional overload in the exercise of teaching activities.

More specifically, the analysis focuses on examining the relationship between institutional demands linked to quality assurance systems and faculty perceptions regarding different aspects of academic work, such as workload, availability of organizational resources, academic climate, and the perceived value of institutional evaluation processes. Through this approach, the study seeks to identify how these organizational dynamics are experienced by faculty members in their everyday practice and how they may influence the emergence of fatigue conditions associated with contemporary academic work.

The study is delimited to the context of the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH), a public higher education institution in Mexico where institutional evaluation and program accreditation processes form part of the regular dynamics of academic management. The analysis focuses on faculty members from various academic units who have participated in these processes, allowing exploration of how the organizational demands associated with evaluation and accreditation are integrated into the development of their professional activities.

It should be noted that this research is conceived as an exploratory study aimed at examining faculty perceptions of the organizational conditions of academic work. Accordingly, the analysis does not aim to conduct a clinical diagnosis of occupational burnout or to assess the presence of burnout syndrome among faculty members. Rather, the study seeks to identify possible conditions of cognitive and emotional overload associated with the organizational design of university work.

From this perspective, faculty perceptions are considered a relevant indicator of how the academic work system operates, as they provide insight into the relationship between institutional demands, available resources, and the actual conditions under which professional work is performed. Analyzing these perceptions from an organizational ergonomics perspective allows faculty fatigue to be understood not

merely as an individual response to work demands but as a phenomenon linked to the structural configurations of academic work in contexts characterized by institutional evaluation processes.

4. METHODOLOGY

4.1 Study design

The research was conducted using a quantitative, exploratory, cross-sectional design, aimed at analyzing faculty perceptions regarding the organizational conditions associated with evaluation and accreditation processes in higher education.

The exploratory approach was adopted because the purpose of the study was to examine trends and patterns in faculty perceptions that may help identify potential organizational configurations associated with conditions of cognitive and emotional overload in academic work. From this perspective, the study is situated within an organizational ergonomics framework, in which workers' perceptions are considered relevant indicators for understanding the interaction between institutional demands, available resources, and the real conditions of professional performance within a work system.

4.2 Participants

The study population consisted of faculty members affiliated with different academic units of the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH) who have participated in institutional evaluation and educational program accreditation processes.

A non-probabilistic purposive sampling strategy was employed. The sample consisted of 283 faculty members who had participated in accreditation and evaluation processes and who belonged to different disciplinary areas. This diversity made it possible to obtain a wide range of perspectives on the organizational conditions associated with these institutional processes.

Participation was voluntary and anonymous, and the data were collected exclusively for academic and research purposes.

4.3 Instrument

Data were collected using a structured Likert-type questionnaire composed of twenty items, designed to explore faculty perceptions of different organizational aspects related to accreditation and institutional evaluation processes.

The instrument was reviewed through expert judgment and subjected to a pilot test prior to its application. The questionnaire was administered through an online form using Google Forms.

The instrument was organized into five analytical dimensions, each of which examines different components of the academic work system..

4.3.1 Understanding of accreditation processes

This dimension evaluates the degree to which faculty members understand the objectives, procedures, and scope of evaluation and accreditation processes. From an organizational perspective, clarity regarding institutional processes is associated with a reduction in role ambiguity and with a better understanding of organizational expectations.

4.3.2 Teaching practice and availability of resources

This dimension explores faculty perceptions regarding the availability of institutional resources, organizational support, and the compatibility between accreditation processes and the development of teaching practice. In terms of the Job Demands–Resources model, this dimension allows the identification of balance or imbalance between institutional demands and the resources available to address them.

4.3.3 Well-being and academic climate

This dimension addresses faculty perceptions of the organizational environment, the balance between work demands and actual working conditions, and the impact of institutional processes on occupational well-being. From the perspective of organizational ergonomics, academic climate can be interpreted as an indicator of the functioning of the work system and of the presence of psychosocial risk factors.

4.3.4 Impact on learning

This dimension examines faculty perceptions regarding the relationship between accreditation processes and their impact on the improvement of teaching and learning processes. It allows identification of whether the administrative demands associated with these processes are perceived as mechanisms that contribute to strengthening educational quality or whether they generate tensions with teaching practice.

4.3.5 Perceived value and critical perspective

This dimension explores the extent to which faculty members attribute meaning and usefulness to institutional evaluation processes, as well as the possible tensions or ambivalences in their assessment of these mechanisms. This component makes it possible to analyze the relationship between the organizational effort required by accreditation processes and the recognition or legitimacy they hold among faculty members.

4.4 Instrument reliability

To assess the internal consistency of the instrument, Cronbach's alpha coefficient was calculated, yielding a value of 0.89, which indicates a high level of reliability and adequate coherence among the items that make up the scale.

This level of reliability suggests that the instrument presents sufficient internal consistency for analyzing faculty perceptions regarding the organizational conditions associated with accreditation and institutional evaluation processes..

4.5 Analysis strategy

The data were analyzed using descriptive statistics, with the aim of identifying general trends in faculty responses across the different dimensions evaluated.

The results were interpreted within the framework of organizational ergonomics, considering the relationship between institutional demands associated with accreditation processes, available organizational resources, and the working conditions perceived by faculty members.

This approach made it possible to analyze faculty perceptions as indicators of how the academic work system operates and of the organizational configurations that may either support or limit occupational well-being in university contexts characterized by institutional evaluation and quality assurance processes.

5. RESULTS

The analysis of the information obtained from the questionnaire administered to faculty members at the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH) made it possible to identify trends in faculty perceptions regarding institutional evaluation and accreditation processes.

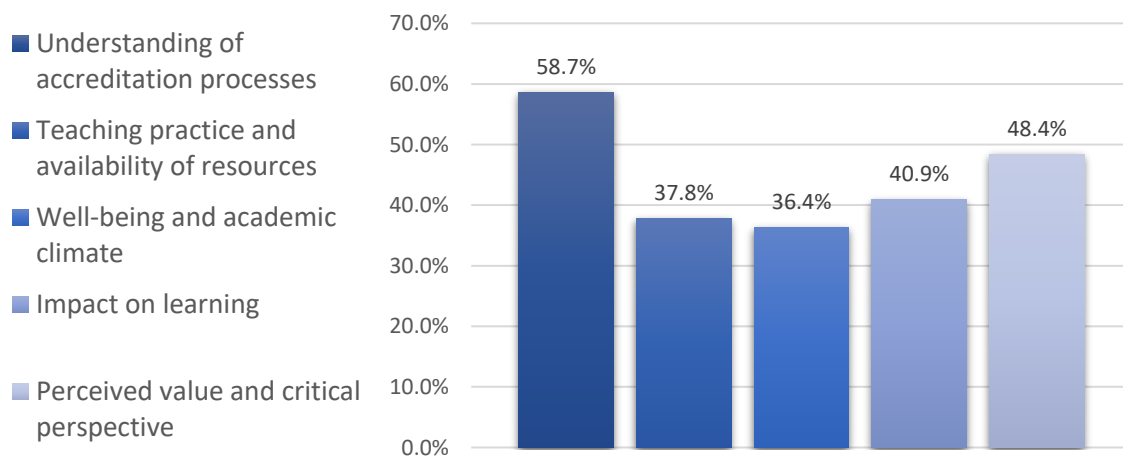


Figure 1. Faculty level of agreement across the analyzed dimensions related to accreditation processes.

To synthesize the general trend observed across the different dimensions analyzed, Figure 1 presents the average percentage of agreement reported by faculty members in each dimension of the instrument.

The results are presented according to the dimensions evaluated in the instrument and interpreted from the perspective of organizational ergonomics and the Job Demands–Resources model, with the aim of understanding how institutional demands associated with accreditation relate to academic working conditions.

5.1 Understanding accreditation processes and cognitive clarity

The results indicate that 58.7% of faculty members report understanding the objectives and criteria of accreditation processes. This suggests that, at the institutional level, faculty possess a relatively clear cognitive understanding of the logic and purpose of these evaluation mechanisms, although differences in knowledge levels are observed depending on the degree of prior participation in such processes.

This finding indicates that, at the institutional level, there is a general understanding of the purpose of evaluation and quality assurance processes. However, from an organizational perspective, conceptual clarity regarding the process does not necessarily imply that its implementation translates into favorable operational conditions for academic work.

In ergonomic terms, understanding the processes may be interpreted as an indicator of cognitive clarity regarding institutional expectations, which contributes to reducing role ambiguity. Nevertheless, this clarity does not eliminate the tensions associated with the administrative workload that these processes may generate in the everyday practice of faculty members.

5.2 Organizational demands and availability of resources

With regard to institutional resources, only 37.8% of faculty members perceive tangible improvements in their teaching practice or in the availability of resources derived from accreditation processes. In other words, the difference between the level of understanding of the process and the perception of available resources suggests a possible dissociation between institutional clarity regarding evaluation and the organizational conditions required for its implementation.

This result indicates the existence of a gap between the institutional demands associated with accreditation and the benefits perceived in real working conditions. From the perspective of the Job Demands–Resources model, this situation may be interpreted as a potential imbalance between the organizational demands introduced by evaluation processes and the resources available to address them.

In contexts where accreditation processes require the preparation of reports, the systematization of evidence, and the monitoring of performance indicators, these activities tend to overlap with the core functions of academic work, such as teaching, research, and academic advising. When these demands are not accompanied by equivalent organizational support, they may contribute to increasing the cognitive and administrative workload of faculty members.

5.3 Well-being and academic climate

Regarding well-being and academic climate, the lowest value among the analyzed dimensions was observed, with 36.4% average agreement. This result indicates that accreditation processes are not widely perceived as factors that have significantly contributed to improving institutional well-being or the academic climate.

The items included in this dimension explore aspects such as the promotion of an institutional culture oriented toward well-being, the balance between the substantive functions of academic work, and the existence of institutional mechanisms to address student needs. Additionally, one of the items evaluates perceptions of the administrative workload associated with accreditation processes.

Overall, the results indicate that a significant proportion of faculty members do not perceive clear improvements in the organizational conditions of academic work derived from accreditation processes. This reinforces the existence of a gap between institutional demands and available organizational resources.

From the perspective of organizational ergonomics, this finding can be interpreted as an indicator of imbalance between institutional demands and organizational resources. When evaluation processes introduce new administrative requirements without substantially modifying working conditions or providing additional institutional support, their impact on faculty well-being may be limited or even perceived as negative.

In this sense, well-being and academic climate represent critical ergonomic indicators of the university work system, as they reflect how organizational dynamics associated with accreditation are translated into the everyday experience of faculty members.

5.4 Perceived impact on student learning

Regarding the impact of accreditation on teaching and learning processes, an average agreement level of 40.9% was observed, indicating moderate positive effects derived from these processes.

The items included in this dimension explore three specific aspects: student participation in the classroom, curricular alignment between courses and graduate profiles, and the incorporation of inclusive and accessible teaching strategies. Together, these elements allow an examination of how accreditation processes influence the pedagogical organization of educational programs.

The results indicate that, from the faculty perspective, accreditation processes have contributed to some extent to strengthening curricular coherence and promoting pedagogical practices oriented toward student participation and inclusion. These aspects are commonly included among the criteria evaluated by accreditation bodies, particularly regarding alignment between educational objectives, teaching strategies, and expected learning outcomes.

However, the observed level of agreement suggests that these effects are not perceived as widespread or fully consolidated among faculty members. This finding can be interpreted as a partial impact of accreditation processes on teaching

practice, where certain pedagogical improvements coexist with organizational tensions derived from the administrative demands associated with these processes.

From an organizational ergonomics perspective, this result suggests that pedagogical improvements associated with accreditation may be limited when administrative demands increase the cognitive workload of faculty members. In other words, although accreditation seeks to strengthen educational quality, its impact on teaching processes may depend on how these mechanisms are integrated into the academic work system.

From this perspective, the findings suggest that improvements in pedagogical processes depend not only on the existence of institutional evaluation but also on the organizational conditions that allow faculty members to develop innovative, inclusive, and learning-centered teaching practices.

5.5 Perceived value of accreditation and faculty critical perspective

The dimension related to perceived value and critical perspective on accreditation processes shows an average agreement level of 48.4%, reflecting a moderate assessment by faculty members regarding the role of these mechanisms in improving educational programs.

The items included in this dimension address various aspects of accreditation processes, including their potential contribution to student performance and retention, institutional transparency regarding progress in accreditation, the perception of accreditation as a bureaucratic requirement, the need for greater faculty participation in these processes, and the overall assessment of their impact on teaching, learning, and academic well-being.

The results show that faculty members recognize certain benefits associated with accreditation processes, particularly in relation to the institutional organization of educational programs and the strengthening of academic monitoring mechanisms. However, this positive assessment coexists with a critical view of certain aspects of the process, especially regarding perceptions of bureaucratization and the limited participation of faculty members in institutional decision-making related to evaluation processes.

This combination of recognition and critique points to the existence of an ambivalent evaluation of accreditation, where faculty members identify both its potential as a tool for educational improvement and the organizational tensions generated by its implementation.

From the perspective of organizational ergonomics, this ambivalence may be interpreted as the result of the interaction between the institutional legitimacy of accreditation processes and their operational impact on the academic work system.

6. DISCUSSION

The results of the study reveal three relevant trends: a general understanding of accreditation processes among faculty members, a limited perception of the organizational resources available to address them, and an ambivalent assessment

of their effects on academic work. Taken together, these findings reveal a structural discrepancy between the institutional clarity of the accreditation process and the organizational conditions under which it is implemented.

From an ergonomic perspective, work should be analyzed as part of a broader system in which organizational structures, institutional norms, and coordination dynamics interact. This study found that activities associated with accreditation tend to overlap with the traditional functions of faculty members, introducing organizational demands that may modify the temporal and cognitive structure of academic work and generate situations of multitasking, time pressure, and expanded responsibilities.

Based on the Job Demands–Resources model, these dynamics can be interpreted as processes of organizational intensification of academic work, in which demands expand without necessarily being accompanied by an equivalent redistribution of organizational resources. When this situation persists over time, perceptions of overload may emerge that affect the work experience of faculty members. In this regard, the low level of agreement observed in the dimension of well-being and academic climate suggests that the organizational transformations associated with accreditation have not translated into perceived improvements in faculty working conditions. Rather, the incorporation of these mechanisms appears to have increased organizational demands without a corresponding redistribution of institutional resources.

To synthesize the relationship among the main dimensions analyzed, Figure 2 presents the discrepancy observed between the institutional understanding of accreditation processes and the organizational conditions related to faculty resources and occupational well-being.

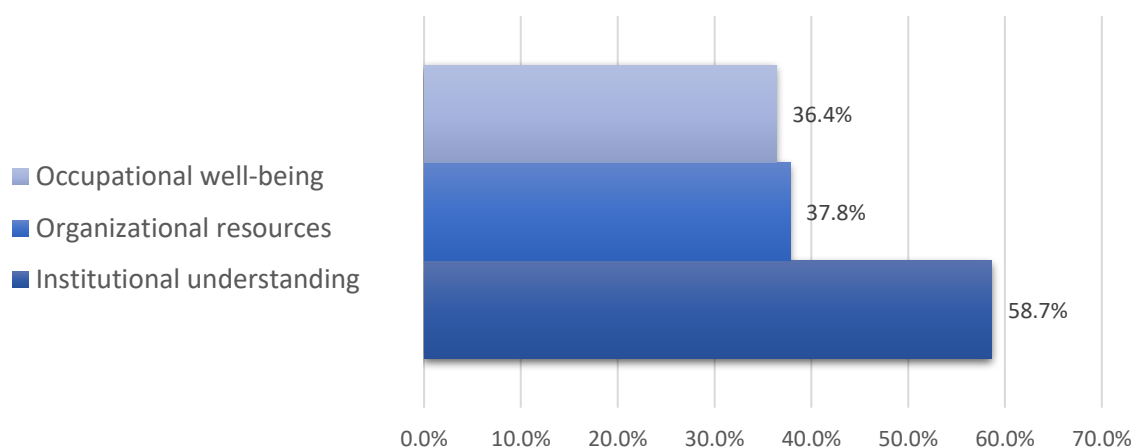


Figure 2. Demands–resources imbalance in accreditation processes.

In the context of the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH), faculty members recognize the potential of accreditation processes to strengthen the organization of educational programs and to promote practices oriented toward academic improvement. However, they also perceive that these mechanisms generate tensions related to administrative workload and the limited

participation of faculty in institutional decision-making. This finding is consistent with the moderate level of agreement observed in the dimension related to impact on learning and is similarly reflected in the perceived usefulness of accreditation, while at the same time revealing a critical stance regarding the operational implementation of evaluation processes.

This ambivalence highlights that the effectiveness of evaluation systems largely depends on the organizational conditions under which these processes are integrated into academic work. In other words, educational quality is not solely the result of the existence of indicators or evaluation mechanisms; it also depends on the alignment between these mechanisms and the actual working conditions of faculty members.

This implies that the sustainability of academic work is a fundamental component of the functioning of university systems. In this context, higher education institutions face the challenge of balancing the demands derived from evaluation systems with the need to guarantee working conditions that allow faculty members to perform their functions effectively and sustainably over time. This issue becomes particularly relevant within the framework of preventing psychosocial risks in the workplace and, from the perspective of organizational ergonomics, broadening the discussion on educational quality by incorporating faculty working conditions as an integral component of institutional evaluation systems.

Similarly, the discussion should be linked to the principles established in the 2030 Agenda for Sustainable Development, particularly with Sustainable Development Goals (SDGs) 3, 4, and 8, which address well-being, quality education, and decent work, respectively. Promoting evaluation systems that incorporate criteria related to the sustainability of academic work strengthens the capacity of higher education institutions to sustain high-quality educational processes in the long term.

Finally, the analysis presented throughout this chapter demonstrates that evaluation and accreditation systems should be understood as elements that actively participate in shaping the organizational configuration of academic work. Incorporating an ergonomic perspective into the design and management of these processes may therefore contribute to the development of evaluation models that are more consistent with the real conditions of university work.

This study has some limitations. The sample was non-probabilistic and is based on faculty perceptions; therefore, the results should be interpreted as exploratory trends. Likewise, the cross-sectional design does not allow causal relationships between organizational demands and faculty fatigue to be established. Despite these limitations, the findings allow the identification of relevant organizational dynamics that help explain the relationship between institutional evaluation systems and academic working conditions.

7. CONCLUSIONS

From the perspective of organizational ergonomics, the analysis developed in this chapter allows cognitive and emotional fatigue in academic work to be understood

as a phenomenon associated with organizational configurations within the context of institutional evaluation. The results show that faculty members recognize the importance of accreditation processes as mechanisms for quality assurance; however, they also reveal that these mechanisms introduce new administrative demands, intensifying academic work and generating organizational tensions.

While faculty members identify positive contributions associated with the organization of educational programs and the formalization and systematization of academic processes, accreditation is also perceived as a procedure that increases administrative workload without translating into visible improvements in working conditions or institutional well-being.

In light of the Job Demands–Resources model and the perspective of organizational ergonomics, the sustainability of academic work should be considered a central component of evaluation and quality assurance systems. In this sense, accreditation processes should be analyzed in relation to the organizational conditions they generate for faculty members.

Accordingly, integrating criteria related to occupational health, workload balance, and the availability of organizational resources into the management of evaluation processes should become a fundamental aspect of strengthening educational quality in higher education institutions. Academic quality should therefore be understood as the capacity of universities to sustain work systems that enable faculty members to carry out their functions in a balanced and sustainable manner.

Finally, this chapter proposes an alternative interpretation of accreditation processes by analyzing them through the lens of organizational ergonomics. This perspective makes it possible to understand that accreditation-oriented evaluation functions not only as a mechanism for certifying educational quality but also as a factor that actively participates in shaping the configuration of academic work. Recognizing this organizational dimension may therefore allow the design of more comprehensive evaluation models capable of aligning the goals of educational quality with the well-being and sustainability of academic work..

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HIKING ERGONOMIC-PHYSIOLOGICAL ANALYSIS WHILE CARRYING A LOAD: INFLUENCE OF TERRAIN (FLAT VS. INCLINED) AND RELATIVE LOAD (15% AND 30%) ON POSTURE, HR AND BORG

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Resumen: El senderismo con carga constituye una actividad locomotora de creciente práctica recreativa que combina desplazamiento prolongado, terreno variable y exigencia musculoesquelética, por lo que representa un campo pertinente para la evaluación ergonómica del trabajo físico. El presente estudio tuvo como objetivo analizar, desde una perspectiva ergonómico-fisiológica, la influencia del terreno (plano vs. inclinado) y de la carga relativa transportada en mochila (15% y 30% del peso corporal) sobre la postura, la frecuencia cardíaca y la percepción subjetiva del esfuerzo en personas adultas con experiencia en senderismo. Se empleó un diseño factorial 2×2 con medidas repetidas y un orden aleatorizado de las condiciones experimentales. La muestra estuvo integrada por cuatro participantes aparentemente sanos, dos hombres y dos mujeres, con experiencia previa en la práctica del senderismo. Las variables fisiológicas incluyeron la frecuencia cardíaca en reposo, la frecuencia cardíaca máxima durante la prueba y la frecuencia cardíaca al finalizar cada recorrido; la percepción del esfuerzo fue valorada mediante la escala de Borg, mientras que la dimensión postural fue analizada por medio de video y evaluada con la herramienta Rapid Entire Body Assessment (REBA).

Los resultados mostraron que las condiciones de mayor demanda, particularmente la combinación de superficie inclinada y una carga equivalente al 30% del peso corporal, incrementaron la exigencia fisiológica y perceptual, expresada en mayores valores de frecuencia cardíaca y puntuaciones más altas en la escala de Borg. Desde el punto de vista ergonómico, el análisis postural evidenció que, en superficie plana, las posturas observadas correspondieron a un nivel de riesgo alto, mientras que, en superficie inclinada, las puntuaciones REBA alcanzaron un nivel de riesgo muy alto. Estos hallazgos sugieren que la inclinación del terreno intensifica la flexión del tronco, modifica la estabilización corporal y eleva la demanda global del sistema musculoesquelético, aun cuando la tarea

corresponde a una actividad recreativa. Asimismo, se observó que, aunque las posturas fueron similares entre géneros, los indicadores fisiológicos y subjetivos mostraron diferencias individuales asociadas con la condición física y la respuesta al esfuerzo. En conjunto, el estudio aporta evidencia para considerar el senderismo con carga como una tarea susceptible de evaluación ergonómica integral y ofrece bases para establecer recomendaciones sobre límites de carga relativa, ajuste de mochila, gestión de pausas y prevención del riesgo musculoesquelético en actividades al aire libre.

Palabras clave: Análisis Ergonómico, Senderismo, Ejecución Humana, Art Tool, Riesgo Musculoesquelético

Relevancia para la ergonomía: El proyecto es relevante desde el punto de vista ergonómico porque operacionaliza el rendimiento humano en el senderismo, mediante la evaluación de la interacción entre la carga interna, valorada con herramientas validadas (HR y Borg), y la organización postural y biomecánica, analizada por vídeo. Los hallazgos pueden orientar lineamientos ergonómicos para la práctica de actividades al aire libre, así como criterios de diseño y ajuste de mochilas, y estrategias preventivas para reducir el riesgo musculoesquelético en poblaciones recreativas, con relevancia regional para México y América Latina.

Abstract: Loaded hiking is a locomotor activity of growing recreational relevance that combines prolonged walking, uneven terrain, and musculoskeletal demands, making it a suitable context for ergonomic evaluation of physical work-like tasks. This study aimed to analyze, from an ergonomic-physiological perspective, the influence of terrain (flat vs. inclined) and relative backpack load (15% and 30% of body mass) on posture, heart rate, and perceived exertion in adults with hiking experience. A 2×2 repeated-measures factorial design with a randomized condition order was used. The sample consisted of four apparently healthy participants, two men and two women, all with previous hiking experience. Physiological variables included resting heart rate, peak heart rate during each trial, and heart rate at the end of each walking bout. Perceived exertion was assessed using the Borg scale, whereas posture was analyzed through video-based observation and evaluated using the Rapid Entire Body Assessment (REBA) method.

The findings showed that the most demanding condition, particularly inclined walking with a backpack load of 30% of body mass, produced higher physiological and perceptual strain, reflected in increased heart rate values and higher Borg ratings. From an ergonomic standpoint, postural assessment indicated that flat-surface hiking generated high REBA risk scores, whereas inclined-surface hiking reached very high risk levels. These results suggest that terrain slope intensifies trunk flexion, reduces body stabilization strategies, and increases the overall musculoskeletal demand, even in recreational outdoor activities. Although the observed postures were similar in both sexes, physiological and subjective indicators revealed individual differences associated with physical condition and response to exertion. Overall, the study supports the view that loaded hiking can be approached as a task requiring integrated ergonomic assessment and provides evidence to guide

recommendations on relative load limits, backpack fitting, rest management, and musculoskeletal risk prevention in outdoor settings. Therefore, the contribution of this work lies in linking external load, terrain demands, physiological response, and whole-body postural risk within a single evaluation framework relevant to work evaluation and occupational ergonomics

Keywords: ergonomic analysis, hiking, human performance, REBA musculoskeletal risk.

Relevance to ergonomics:

The project advances ergonomics by operationalizing human performance in hiking as the interaction between internal load, assessed through HR and Borg, and postural and biomechanical organization, examined through video analysis. The findings can inform ergonomic guidelines for outdoor activities, backpack design and fitting criteria, and preventive strategies aimed at reducing musculoskeletal risk in recreational populations, with regional relevance for Mexico and Latin America.

1. INTRODUCTION

Hiking has become one of the most widely practiced outdoor activities. Available evidence worldwide shows: (a) a sustained increase in the number of participants and visits to natural areas, (b) a parallel increase in the demand for rescue services and injury care, and (c) a predominance of lower-extremity injuries, especially to the ankle and knee, which justifies ergonomic research focused on posture, fatigue, and external loading (Braybrook et al., 2023; CRS, 2024; Deutscher Wanderverband, 2024; Outdoor Foundation, 2025).

Across Mexico and Latin America, hiking has also expanded as a leisure physical activity and a form of nature-based tourism, although less information is available. In Mexico, INEGI reported an increase in the proportion of physically active adults from 39.8% in 2023 to 41.1% in 2024, thereby enlarging the potential participant pool (INEGI, 2025). Protected-area visitation in the region is also substantial; for example, Brazil reported 25.5 million visits to federal conservation units in 2024 (ICMBio, 2025), and Costa Rica recorded 2,611,643 visits to protected wild areas in 2024 (ICT, 2025). This growth increases population exposure to walking-related risks on sloped terrain, especially when backpack loads are carried. Experimental evidence on load carriage shows greater physiological demand and biomechanical changes during level and uphill walking, which may contribute to fatigue, postural compensation, and musculoskeletal risk (Pinedo-Jauregi et al., 2022; Matur et al., 2025).

Hiking is a locomotor activity that combines prolonged walking, variable terrain, and, in many cases, external load carriage, all of which create meaningful ergonomic and physiological demands. Recent evidence has shown that load carriage during walking can alter spatiotemporal gait parameters, postural organization, muscular activity, and physiological responses, particularly when

terrain conditions become more challenging, such as during uphill walking. A recent systematic review published in *Applied Ergonomics* concluded that load carriage meaningfully affects biomechanical and physiological responses during walking and highlighted changes in gait and body mechanics as central elements of this demand (Hudson et al., 2024). These findings are especially relevant for hiking, where walking is performed over prolonged periods and often under conditions of incline, instability, and backpack loading.

From an ergonomic standpoint, hiking while carrying a load may be interpreted as a whole-body task in which trunk inclination, lower-limb support, neck alignment, arm position, and load handling interact continuously. In this context, the Rapid Entire Body Assessment (REBA) is a potentially valuable method because it allows the evaluator to classify postural risk through an integrated analysis of the neck, trunk, legs, and upper extremities, while also considering load or force and coupling conditions. Although REBA was originally developed for occupational settings, recent research has demonstrated that it can be successfully extended to dynamic and sport-related activities. For example, Fehringer et al. (2025) applied REBA to professional dance training using motion-capture data and showed that the method can categorize whole-body ergonomic risk even in highly dynamic movement contexts. This is especially important for hiking research, because the activity involves repetitive locomotion combined with transient postural adaptations that resemble dynamic work rather than static occupational postures.

The relevance of REBA for hiking is further strengthened by recent methodological developments. Jiao et al. (2024) proposed an improved REBA model based on deep learning, arguing that conventional two-dimensional posture-based assessment may be insufficient to capture the complexity of three-dimensional movements and dynamic postures. Their work supports the contemporary value of REBA not only as a traditional screening tool, but also as a flexible ergonomic framework that can be adapted to more complex movement environments. This is particularly pertinent to hiking with a load, where postural responses are not fixed but are continuously adjusted according to terrain slope, body-mass distribution, step pattern, and fatigue. Thus, REBA offers a practical way to translate observed postural adaptations into an interpretable ergonomic risk score that can complement physiological indicators.

In studies of load carriage, the combined effects of relative load and terrain are especially important. Literature has consistently reported that walking with an external load modifies gait mechanics and increases physiological cost, while steeper gradients further amplify muscular and biomechanical demands. Hudson et al. (2024) emphasized that load-carriage research has documented meaningful differences in physiological and biomechanical responses during walking, including altered movement strategies and greater physical demand. In hiking, these effects may be expected to intensify as terrain changes from flat to inclined and as carried load increases from moderate to relatively high levels, such as 15% and 30% of body mass. Under these conditions, postural compensations such as greater trunk lean, modified lower-limb support, and changes in upper-body stabilization become likely, making REBA especially useful as a whole-body observation method.

However, REBA should not be viewed as a substitute for physiological or

perceptual indicators such as heart rate (HR) or Borg's rating of perceived exertion, but rather as a complementary ergonomic tool. In a hiking context, HR reflects cardiovascular demand, Borg captures subjective exertion, and REBA provides a structured interpretation of postural risk. The integration of these dimensions is methodologically valuable because hiking with a load is simultaneously a biomechanical, physiological, and ergonomic phenomenon. While the current literature provides substantial evidence on the physiological and biomechanical effects of load carriage, fewer studies have explicitly incorporated an observational ergonomic tool such as REBA into the assessment of sport-related locomotor activities. This creates an important opportunity to expand work-evaluation approaches into physically demanding recreational and outdoor contexts.

Therefore, the present study is grounded in the premise that hiking with a load can be meaningfully analyzed through an ergonomic-physiological approach. Specifically, examining the influence of terrain (flat vs. inclined) and relative load (15% and 30%) on posture, heart rate, and perceived exertion may provide a more comprehensive understanding of the demands imposed by hiking. Within this framework, REBA is proposed as a useful tool for identifying and comparing postural risk during hiking-related tasks, thereby strengthening the evaluation of work-like physical demands in outdoor and sport settings.

2. OBJECTIVES

To quantify the effects of terrain (level vs. incline) and relative backpack load (15% vs. 30% of body mass) on:

- a. Physiological response – heart rate
- b. Perceived exertion – Borg scale score
- c. Posture changes and accumulated time spent in risk postures, using video-based analysis and linking these findings to physiological and perceptual indicators.

2.1 Delimitation (Scope):

The study is experimental and consists of continuous hiking bouts lasting 15 to 30 minutes under two terrain conditions (level and a constant recorded incline; operational reference: 8–12% and two load conditions (15% and 30% of body mass), using a standardized backpack fit (shoulder straps and hip belt). The protocol focuses on controlled walking on a defined trail; it does not include running, highly technical terrain, high altitude, or loads above 30% of body mass. Participants are apparently healthy adults and hiking enthusiasts with previous experience, appropriate footwear type, pole use, no injuries during the preceding 12 months, and no reported cardiometabolic conditions.

3. METHODOLOGY

A 2×2 within-subject factorial design was used, with a randomized order of the four conditions (level–15%, level–30%, incline–15%, and incline–30%).

Subjects were required to sign an informed-consent form before participating in the trials. The documents specified the study objective, the activities to be undertaken, the expected risks, discomforts, and benefits, confidentiality, data handling procedures, voluntariness, the right to withdraw, and the statement of consent.

Rest periods and recovery criteria based on heart rate and Borg ratings were applied between conditions to control cumulative fatigue. Physiological outcomes include resting HR, peak HR during each bout, and HR at the end of each bout. The perceptual outcome was the Borg Rating of Perceived Exertion (RPE) recorded at the end of each condition. Postural outcomes were obtained from sagittal-plane video to estimate segment and joint angles (trunk, hip, knee, and ankle), compute an observational posture-risk score (REBA), and quantify the percentage of time spent in trunk-flexion ranges associated with higher demand. Statistical analysis relied on repeated-measures models to assess the main effects of terrain and load, as well as their interaction, with effect sizes and confidence intervals reported.

4. RESULTS

Four subjects participated in the study; their general characteristics are shown in Table 1. The results indicate that Heart rate and Borg ratings increased with terrain inclined and higher load, with the combined condition (incline + 30%) yielding the highest demand. Evidence indicates that uphill walking and heavier loads increase physiological stress and perceived exertion (Pinedo-Jauregi et al., 2022). From biomechanical considerations, greater forward trunk lean, hip, knee, and ankle adjustments, as well as greater asymmetry and variability, are expected under higher loads, consistent with reported changes in joint range of motion and muscle activity during level and inclined walking with backpacks (Matur et al., 2025). In addition, research on muscle synergies suggests that backpack carriage modifies coordination patterns, supporting the hypothesis of motor reorganization under load (Marino et al., 2024). Overall, posture-risk scores and time spent on risk postures are expected to increase with both load and incline and to correlate with HR and Borg.

Table 1. General characteristics of the subjects.

SUJETOS	EDAD	SEXO	ESTATURA	PESO
H1	44	M	1.8	91
H2	62	M	1.65	80
M1	51	F	1.7	69
M2	51	F	1.68	69

All four subjects signed an informed-consent form and reported no injuries during the prior 12 months. Regarding hiking experience, three participants reported more than twenty-four months of practice, whereas H2 reported between 6 and 24 months of experience. The female participants practice hiking at least once a week. Subject H1 hikes two to three times per week, whereas Subject H2 hikes at least once a month. All participants reported using appropriate equipment, including shoes, poles, and a backpack. On average, the women carry five kilograms, and the men carry eight kilograms in their backpacks while practicing this activity.

The results of the ergonomic analysis for each task were obtained using the Rapid Entire Body Assessment (REBA) (McAtamney & Corlett, 1995). It is important to note that the observed postures were similar in both sexes; therefore, the REBA results were also similar, although men and women showed different physiological and subjective responses. The results for hiking on a flat surface with different backpack weights are shown in Figure 1. Figure 2 presents examples of the postures adopted by the subjects during the trials, on which the REBA scores were based. The scores obtained corresponded to a high-risk level.

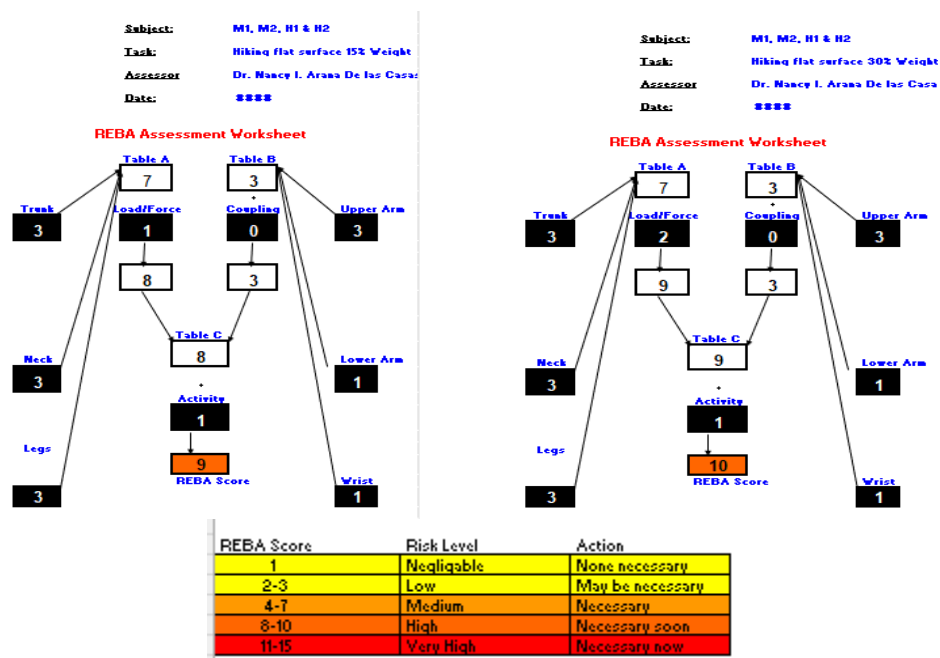


Figure 1. REBA results in hiking on a level surface with different backpack weights (McAtamney & Corlett, 1995)

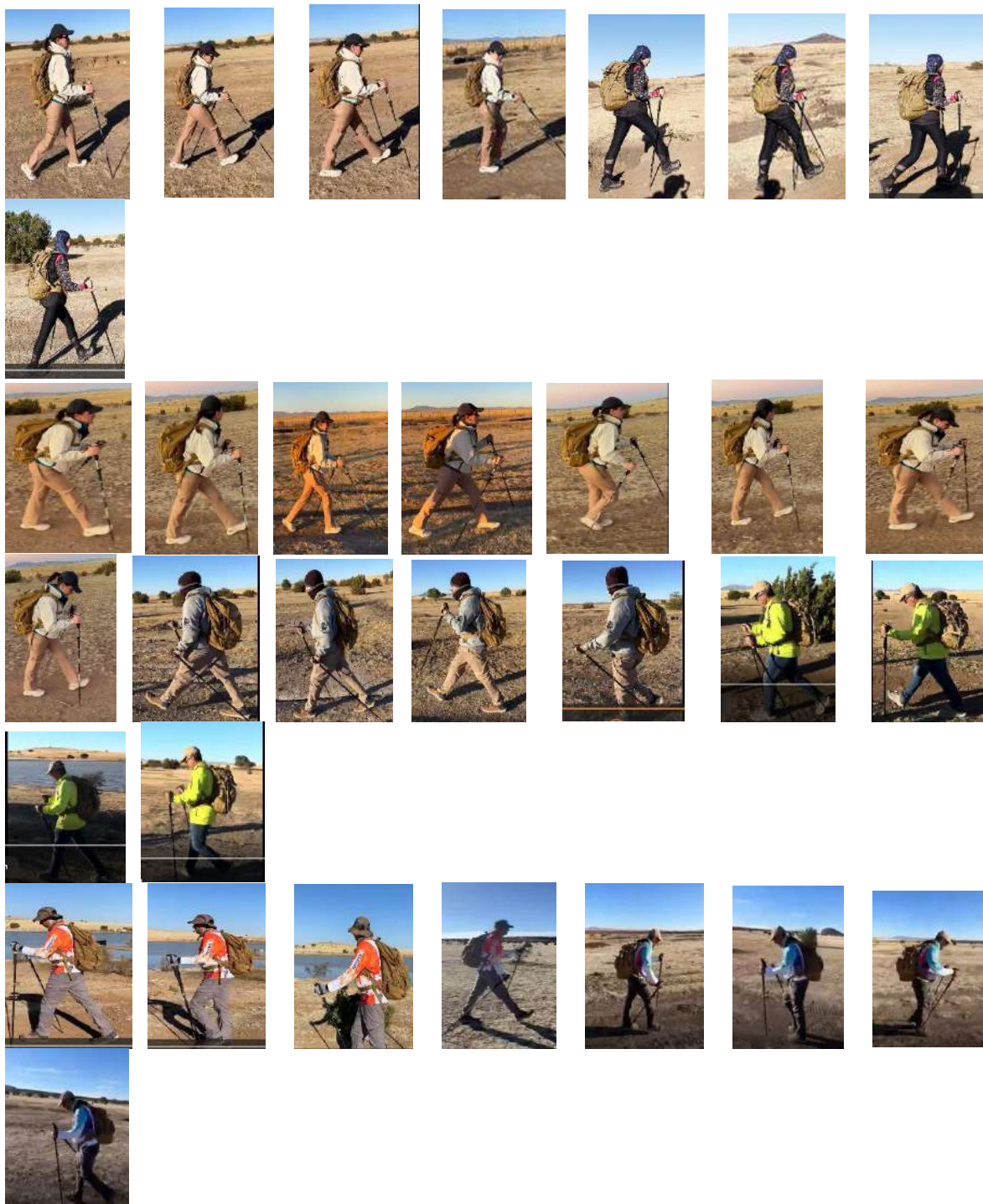


Figure 2. Examples of the subject's postures while hiking on a level surface with different backpack weights (McAtamney & Corlett, 1995)

The REBA results for hiking on an inclined surface with different backpack weights are shown in Figure 3. Figure 4 presents examples of the postures adopted by the subjects during the trials, on which the REBA scores were based. The scores

obtained corresponded to a very high-risk level.

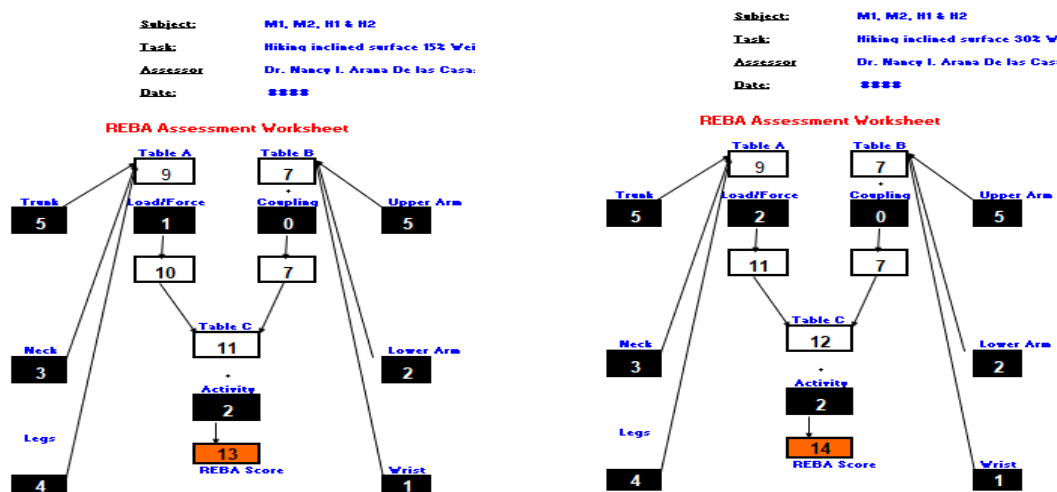
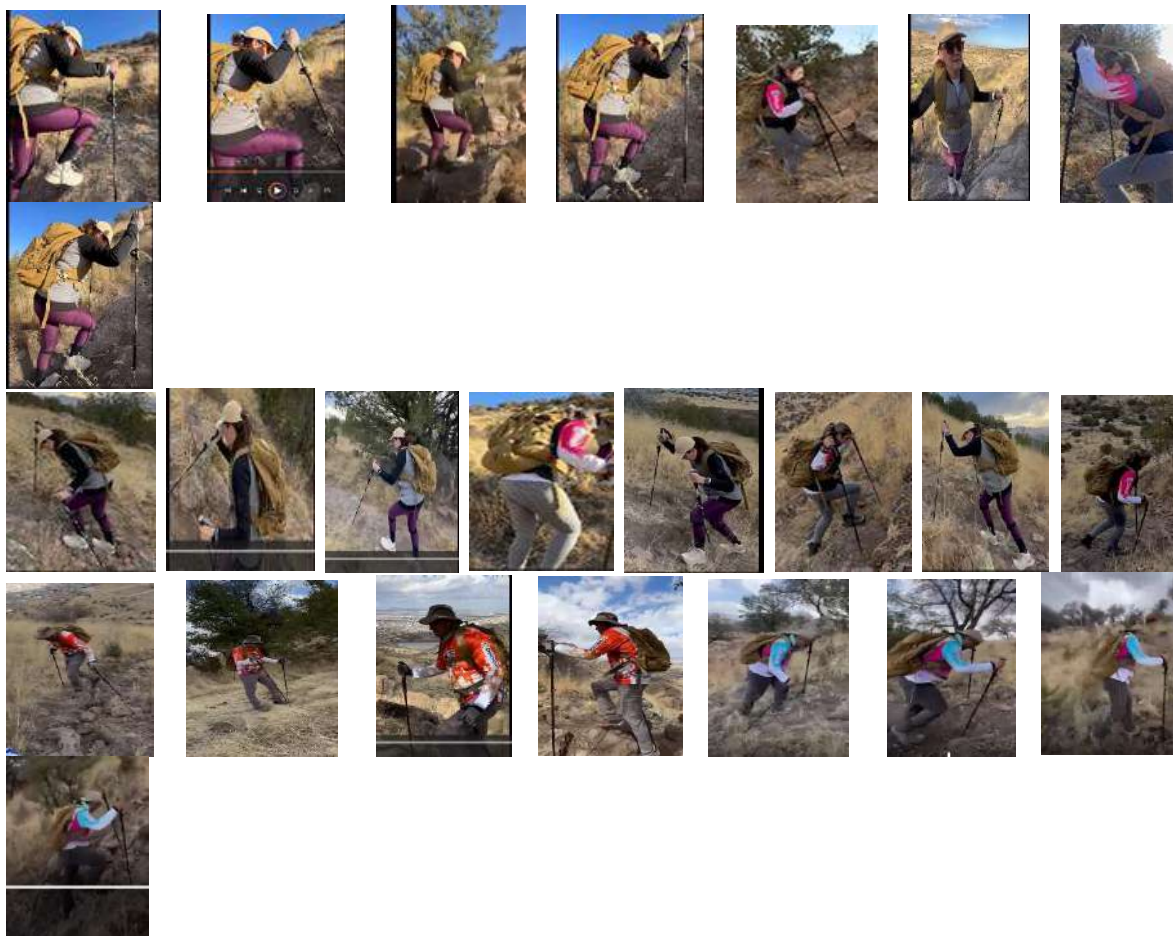


Figure 3. REBA results for hiking on an uphill surface with different backpack weights (McAtamney & Corlett, 1995)



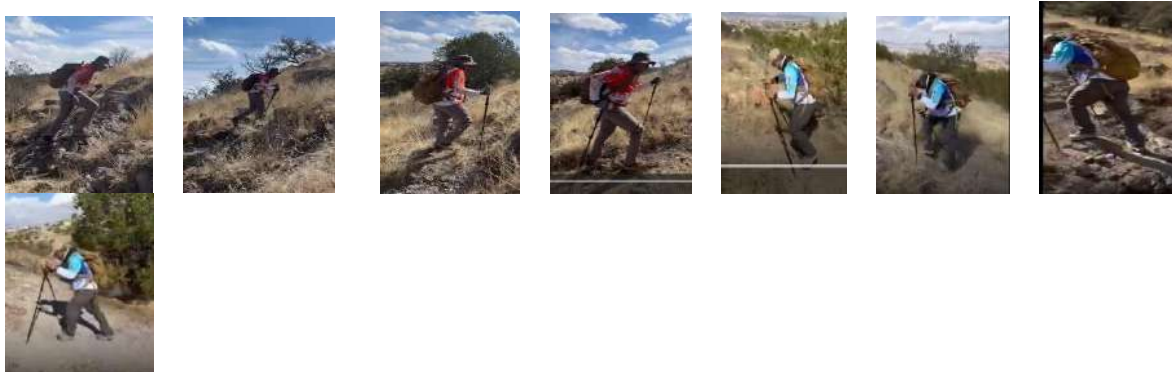


Figure 4. Examples of the subject's postures while hiking on an inclined surface with different backpack weights (McAtamney & Corlett, 1995)

As expected, physiological data, specifically heart rate, increased as the load increased, and the same pattern was observed for the Borg scale. These differences were also observed when comparing the level and inclined surfaces. The data obtained in the trials are shown in the following tables.

Table 2. Physiological measurements and effort perception in a flat surface trail and 15% backpack weight.

SUBJECT	RESTING HEART RATE	MAXIMUM HEART RATE DURING THE TEST	HEART RATE AT THE END OF THE TEST	BORG SCALE RESULT (RPE)
H1	75	106	131	2
H2	80	106	112	2
M1	76	114	139	4
M2	79	99	127	3

Table 3. Physiological measurements and effort perception in a flat surface trail and 30% backpack weight.

SUBJECT	RESTING HEART RATE	MAXIMUM HEART RATE DURING THE TEST	HEART RATE AT THE END OF THE TEST	BORG SCALE RESULT (RPE)
H1	85	109	114	6
H2	113	138	141	7
M1	78	137	133	6
M2	73	104	140	6

Table 4. Physiological measurements and effort perception in an inclined surface trail and 15% backpack weight.

SUBJECT	RESTING HEART RATE	MAXIMUM HEART RATE DURING THE TEST	HEART RATE AT THE END OF THE TEST	BORG SCALE RESULT (RPE)
H1	82	110	146	5
H2	121	156	160	6
M1	82	90	101	6
M2	82	135	135	5

Table 5. Physiological measurements and effort perception in an inclined surface trail and 30% backpack weight.

SUBJECT	RESTING HEART RATE	MAXIMUM HEART RATE DURING THE TEST	HEART RATE AT THE END OF THE TEST	BORG SCALE RESULT (RPE)
H1	81	142	145	7
H2	112	161	160	7
M1	84	122	130	7
M2	85	145	165	7

5. CONCLUSIONS

The present study supports the interpretation of loaded hiking as a work-like physical task that can and should be examined through an integrated ergonomic-physiological framework. Within the tested conditions, the combination of external load and terrain slope increased physiological demand and perceived exertion, while postural assessment showed that level walking with a backpack already represented a high-risk condition and uphill walking escalated to a very high postural-risk level. These findings are consistent with recent evidence showing that backpack load and gradient jointly increase cardiovascular strain, oxygen demand, and perceived effort during walking, with slope and load acting in an additive manner that may compromise sustainable work capacity when exposure is prolonged (Hudson et al., 2024; Pinedo-Jauregi et al., 2022). From the perspective of work evaluation, the present results reinforce that hiking underload is not merely a recreational movement pattern, but a demanding locomotor task in which ergonomic risk rises as environmental and load constraints intensify.

The conclusions are also relevant because they show that postural risk remains substantial even when the activity is performed by apparently healthy adults with prior hiking experience. In practical terms, this means that experience alone does not eliminate the mechanical demands imposed by trunk inclination, lower-limb stabilization, and continuous adaptation to carried mass. Recent biomechanical studies have shown that backpack carriage alters spinal mobility, hip rotation, muscle activation patterns, and gait organization, indicating that individuals redistribute movement and muscular effort to cope with the external load (Matur et al., 2025). Similarly, evidence on motor control has shown that backpack carriage modifies coordination strategies during walking, suggesting that load does not simply increase effort linearly, but also reorganizes the way movement is controlled (Marino et al., 2024). In the context of the present study, these mechanisms help explain why higher REBA scores and greater physiological strain emerged together, particularly under inclined conditions.

A major contribution to this work is the use of REBA as a whole-body ergonomic tool in an outdoor dynamic activity. Although REBA was originally developed for occupational environments, recent literature indicates that it can be meaningfully extended to dynamic and sport-related contexts when the goal is to classify whole-body postural demand and identify high-risk movement exposure. Research using motion-capture-supported REBA in highly dynamic activities has

shown that the method remains useful for characterizing musculoskeletal risk beyond traditional industrial tasks, while advances in three-dimensional posture estimation have strengthened its applicability in complex movement settings (Fehring et al., 2026; Jiao et al., 2024). Therefore, the present results support the methodological value of REBA as a complementary instrument for work evaluation in hiking and related outdoor activities, particularly when it is interpreted alongside heart rate and Borg ratings rather than as a stand-alone indicator.

From an applied standpoint, the findings support several preventive implications. First, relative backpack load should be treated as a controllable ergonomic factor, especially when hiking takes place on inclines or for prolonged durations. Second, route slope should be considered together with load when determining safe exposure, since recent evidence indicates that gradient amplifies the physiological burden of load carriage and can reduce sustainable performance time (Pinedo-Jauregi et al., 2022). Third, backpack fitting, pace regulation, scheduled recovery periods, and progressive conditioning should be incorporated into risk-management strategies for recreational hikers and for occupations involving uphill load carriage. These recommendations are also aligned with recent reviews showing that load carriage affects gait mechanics and that relevant differences in response may emerge according to body characteristics and movement strategies, even when sagittal-plane posture appears similar between sexes (Hudson et al., 2024).

In summary, the study demonstrates that terrain and relative load should be interpreted as interacting ergonomic determinants of postural and physiological demand during hiking. The combination of increased heart rate, higher perceived exertion, and elevated REBA scores under inclined and heavier-load conditions indicates that musculoskeletal and cardiovascular strain converge in this activity, which strengthens its relevance within the topic of work evaluation. The chapter therefore contributes evidence that loaded hiking can be assessed with the same ergonomic rigor applied to occupational tasks, expanding the scope of occupational ergonomics toward outdoor, recreational, and hybrid work-like contexts. Future studies should increase sample size, include longer exposure times, incorporate direct metabolic and electromyographic measures, and examine sex-specific adaptation, backpack design, and real-terrain variability in order to refine ergonomic recommendations and improve prevention strategies for load-carrying activities (Braybrook et al., 2023; Grigg et al., 2025; Hudson et al., 2024).

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ACCREDITATION PROCESSES AND ORGANIZATIONAL ERGONOMICS IN ACADEMIC WORK: EMPIRICAL EVIDENCE FROM THE UNIVERSIDAD MICHOACANA DE SAN NICOLÁS DE HIDALGO

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Resumen: En las últimas décadas, la educación superior ha intensificado los sistemas de evaluación y acreditación. Este capítulo analiza, desde la ergonomía organizacional, cómo estas dinámicas se integran al trabajo académico y se asocian con percepciones sobre recursos, clima académico y distribución de cargas en docentes universitarios.

Se aplicó una encuesta a docentes de diversas unidades académicas de la Universidad Michoacana de San Nicolás de Hidalgo (UMSNH) (n=283) para explorar comprensión de la acreditación, recursos para la práctica docente, bienestar/clima académico, impacto en el aprendizaje y valor percibido/visión crítica. En México, estos procesos se han reforzado con marcos normativos y dispositivos de coordinación nacional orientados a la mejora continua.

Desde la ergonomía organizacional, se analiza la integración de tareas de acreditación al sistema de trabajo académico y su relación con percepciones sobre recursos, clima y prácticas docentes.

Los docentes reportan alta comprensión de la acreditación, pero valoraciones más bajas sobre recursos y bienestar/clima, lo que sugiere tensiones entre demandas de acreditación y condiciones organizacionales del trabajo académico.

Palabras clave: *Procesos de acreditación, ergonomía organizacional, trabajo académico, evaluación de la educación superior.*

Relevancia para la ergonomía: La ergonomía organizacional permite analizar los procesos de acreditación como parte del diseño del sistema de trabajo universitario, pues incorporan tareas de gestión, redistribuyen responsabilidades y demandan coordinación. Este enfoque amplía la evaluación de la 'calidad' al considerar sus implicaciones sobre la organización del trabajo académico.

Estos procesos introducen tareas de gestión (evidencias, informes, seguimiento) que se superponen a docencia/investigación y pueden alterar cargas y tiempos. En el caso estudiado, la acreditación se vive como demanda sin ajuste proporcional de tiempos/recursos, lo que apunta a una brecha entre diseño formal y condiciones reales del trabajo académico.

El capítulo propone incorporar la evaluación/acreditación como variable organizacional en estudios de ergonomía organizacional en IES, para analizar cómo políticas, gestión y coordinación configuran condiciones del trabajo docente. Se destacan implicaciones para distribución del trabajo, coordinación y sostenibilidad del trabajo docente. Incorporar criterios ergonómicos permitiría diseñar evaluaciones más consistentes con la realidad operativa (tiempos, recursos, cargas) del trabajo académico.

Abstract: In recent decades, higher education has intensified evaluation and accreditation systems. This chapter analyzes, from an organizational ergonomics perspective, how these dynamics are integrated into academic work and how they relate to perceptions of resources, academic climate, and workload distribution among university faculty.

A survey was administered to faculty members from various academic units of the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH) (n = 283) to explore their understanding of accreditation, resources available for teaching practice, well-being/academic climate, perceived impact on learning, and perceived value/critical perspectives.

In Mexico, these processes have been reinforced through regulatory frameworks and national coordination mechanisms aimed at continuous improvement.

From the perspective of organizational ergonomics, the integration of accreditation tasks into the academic work system is analyzed, along with their relationship to perceptions of resources, climate, and teaching practices.

Faculty report a high level of understanding of accreditation; however, they express lower evaluations regarding resources and well-being/academic climate, suggesting tensions between accreditation demands and the organizational conditions of academic work

Keywords: *Accreditation processes, organizational ergonomics, academic work, higher education evaluation.*

Relevance to Ergonomics: Organizational ergonomics makes it possible to analyze accreditation processes as part of the design of the university work system, as they incorporate management tasks, redistribute responsibilities, and require coordination. This perspective broadens the evaluation of “quality” by considering its implications for the organization of academic work.

These processes introduce management tasks (evidence compilation, reports, monitoring) that overlap with teaching and research activities and may alter workloads and time allocation. In the case studied, accreditation is experienced as an additional demand without a proportional adjustment in time and resources, pointing to a gap between formal design and the real conditions of academic work.

The chapter proposes incorporating evaluation and accreditation as organizational variables in studies of organizational ergonomics in higher education institutions, in order to analyze how policies, management, and coordination shape the conditions of academic work. Implications are highlighted for workload distribution, coordination, and the sustainability of faculty work. Incorporating ergonomic criteria could allow for the design of evaluation processes that are more consistent with the operational realities (time, resources, and workloads) of academic work.

1. INTRODUCTION

Evaluation and accreditation have become established as quality assurance instruments in higher education; in addition, they reconfigure internal practices by requiring evidence, reports, and indicators for decision-making (Harvey & Green, 1993; Dill & Beerkens, 2013).

International organizations have noted that quality assurance can strengthen governance and transparency; however, its design must take into account the institutional conditions under which it operates (OECD, 2019; UNESCO, 2022).

In Mexico, the General Law of Higher Education (LGES) reinforces evaluation and continuous improvement as guiding principles of the system and promotes instruments to assess the performance of institutions and academic programs, addressing quality, equity, and social relevance (Cámara de Diputados, 2021).

Within this framework, the Higher Education Evaluation and Accreditation System (SEAES) has been strengthened, aiming to articulate evaluation mechanisms and to broaden the notion of quality by incorporating institutional development, social responsibility, and the conditions under which core university functions are carried out (SEAES, 2023).

These systems have strengthened planning and monitoring; however, they have also added management tasks (reports, evidence, indicators) that become integrated into academic work alongside teaching, research, and mentoring activities.

In this context, it is relevant to analyze how accreditation, beyond evaluating quality, also influences the organization of academic work. The expansion of quality assurance has introduced additional documentation and reporting tasks that contribute to shaping the academic work system (Dill & Beerkens, 2013).

At the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH), accreditation and institutional evaluation are regular practices within academic management; therefore, it constitutes a relevant case for studying how these processes are integrated into academic work and how they relate to faculty working conditions and the academic climate/well-being of university professors..

2. EVALUATION AND QUALITY ASSURANCE IN HIGHER EDUCATION

2.1 Evaluation and Governance in Higher Education

Institutional evaluation and quality assurance systems have become central components of contemporary governance in higher education. Beyond their technical function of verifying academic standards, these mechanisms form part of a broader set of transformations in the ways university systems are regulated, managed, and evaluated by the State and by external organizations.

One of the central debates in the literature on educational quality concerns the very definition of “quality.” Harvey and Green (1993) noted early on that quality in higher education cannot be defined unambiguously, as it may be interpreted as academic excellence, fitness for purpose, compliance with standards, or as a continuous process of institutional improvement. This multiplicity of meanings has influenced the design of evaluation and accreditation systems in different countries, since each perspective implies distinct criteria and mechanisms of assessment.

Within the context of current reforms in higher education, several authors have pointed out that quality assurance systems serve a dual function. On the one hand, they aim to ensure institutional accountability to society and regulatory bodies; on the other hand, they seek to promote institutional improvement processes that strengthen the academic performance of universities. Dill and Beerkens (2013) explain that these systems operate as public policy instruments designed to balance both dimensions: external oversight of the university system and the development of internal organizational learning processes within institutions.

From a governance perspective, the expansion of evaluation systems is also linked to broader transformations in the management of higher education. Hazelkorn (2015) notes that in many countries universities have moved from operating within relatively autonomous frameworks to functioning within systems increasingly guided by indicators, comparative evaluations, and mechanisms for monitoring institutional performance. In this context, evaluation and accreditation systems not only generate information about educational quality but also influence the ways in which institutions organize their academic and administrative processes, thereby affecting the everyday organization of academic work.

International organizations such as the OECD have noted that quality assurance can strengthen governance through the production of systematic information;

however, they also warn that its design must take into account institutional conditions and avoid approaches limited to the formal compliance with indicators (OECD, 2019).

From this perspective, evaluation and accreditation systems can be understood as instruments of educational regulation, but also as mechanisms that influence the way higher education institutions organize their academic and administrative processes. Analyzing these mechanisms from an organizational perspective allows for a better understanding of their implications for the internal dynamics of universities and for the conditions under which academic work is carried out..

2.2 Evaluation Policies in Mexico

The development of evaluation systems in Mexican higher education must be understood within the context of the institutional transformations experienced by the university system since the late twentieth century. During the 1990s, various reforms aimed at strengthening educational quality promoted the creation of mechanisms for institutional evaluation and the accreditation of academic programs. These initiatives responded both to the expansion of the university system and to the need to establish criteria that would allow the performance of higher education institutions (HEIs) to be assessed in an increasingly complex and diverse environment.

In Latin America, these processes were linked to reforms aimed at improving the regulation and quality of higher education systems. Rama (2009) notes that, beginning in the 1990s, numerous countries in the region started to develop national systems of evaluation and accreditation in order to establish mechanisms for supervising the quality of academic programs and strengthening public trust in university institutions. Within this regional framework, Mexico promoted several initiatives aimed at institutionalizing the evaluation of higher education.

Among the most relevant mechanisms developed in the country are the Interinstitutional Committees for the Evaluation of Higher Education (CIEES), created to conduct diagnostic evaluations of academic programs and to promote processes of institutional improvement. At the same time, the Council for the Accreditation of Higher Education (COPAES) was established as the body responsible for recognizing accrediting agencies tasked with evaluating the quality of educational programs in different disciplinary areas. Through these instruments, institutional evaluation began to consolidate as part of the organizational culture of Mexican HEIs. However, the evolution of these systems has also been accompanied by debates regarding their scope and their effects on the functioning of universities.

Some authors have pointed out that evaluation and accreditation processes have contributed to strengthening academic planning and the systematization of institutional information; however, they have also generated new challenges related to the way these mechanisms are integrated into the everyday dynamics of academic work (Rama, 2009; Dill & Beerkens, 2013).

In recent years, the regulatory framework for higher education in Mexico underwent significant changes with the enactment of the General Law of Higher Education (LGES) in 2021. This legislation establishes evaluation and continuous improvement as fundamental principles of the higher education system and

recognizes the need to strengthen institutional mechanisms that allow the performance of institutions and academic programs to be assessed. In this regard, the LGES states that evaluation processes should contribute to institutional development and to strengthening the core functions of universities, rather than serving solely as mechanisms of accountability (Cámara de Diputados, 2021).

As part of this new institutional framework, the Higher Education Evaluation and Accreditation System (SEAES) was created with the aim of articulating the different existing evaluation mechanisms and promoting a comprehensive vision of educational quality. SEAES proposes a model that seeks to broaden the traditional perspective of evaluation by incorporating dimensions related to institutional development, social responsibility, and the conditions under which the core functions of higher education institutions are carried out (SEAES, 2023).

This approach is particularly relevant because it introduces the idea that the evaluation of higher education cannot be limited exclusively to the analysis of academic results, but must also consider the institutional conditions that influence the functioning of universities. From this perspective, evaluation and accreditation systems can be understood as tools that, in addition to assessing the quality of academic programs, influence the way institutions organize their academic, administrative, and management processes.

Analyzing evaluation policies in Mexico from this perspective makes it possible to understand how accreditation systems are integrated into the organizational dynamics of higher education institutions and how these mechanisms may influence the configuration of academic work within universities.

At the institutional level, evaluation and accreditation processes have also been progressively incorporated by universities as part of their strategies for academic strengthening. At the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH), accreditation was consolidated in 2007 with the accreditation of the Chemical Engineering Program by the Council for the Accreditation of Engineering Education (CACEI), an accrediting body recognized by COPAES. This process represented a significant step in the institutionalization of an evaluation culture within the university, as it promoted the revision of study plans, the systematization of academic evidence, and the strengthening of continuous improvement processes within the program.

Over time, the Chemical Engineering program has maintained a sustained trajectory in these evaluation processes, currently achieving its fourth accreditation, now under a scheme of international recognition. In recent years, UMSNH has reported a high proportion of student enrollment in programs with recognized quality standards; additionally, the university participated in the 2023 SEAES call.

These experiences illustrate how accreditation becomes integrated into institutional dynamics and into the organization of academic programs.

3. ORGANIZATIONAL ERGONOMICS AND ACADEMIC WORK

3.1 Organizational ergonomics as an analytical approach

Ergonomics has progressively expanded its field of study beyond the analysis of the physical conditions of work to incorporate an understanding of the organizational systems within which work activities take place.

While early ergonomic approaches focused primarily on the relationship between individuals and the physical elements of their work environments, the development of organizational ergonomics has made it possible to integrate the analysis of structural factors, management processes, and coordination dynamics within organizations.

According to Dull and Neumann (2009), organizational ergonomics focuses on the design and optimization of sociotechnical systems, considering the interaction among people, tasks, technologies, and organizational structures. From this perspective, work is understood as the result of the interaction among multiple organizational components, which implies that working conditions do not depend solely on the individual characteristics of workers, but also on the ways in which organizations design their processes, distribute responsibilities, and establish coordination mechanisms.

This perspective is particularly useful for analyzing complex organizational contexts in which work activities are carried out through multiple interdependent processes. In this sense, organizational ergonomics makes it possible to examine how specific institutional configurations influence the way work is organized and the conditions under which individuals carry out their professional activities.

3.2 Universities as complex work systems

Higher education institutions (HEIs) can be understood as complex organizations in which various academic, administrative, and management functions converge. In the university context, faculty members participate in a wide range of activities including teaching, research, mentoring, academic management, and participation in institutional processes. These functions are not developed in isolation but within organizational structures that articulate institutional policies, management processes, and coordination dynamics among different actors.

Several studies have indicated that academic work has undergone significant transformations in recent decades as a result of changes in higher education policies and university management models. Enders and de Weert (2009) note that the expansion of evaluation mechanisms, accountability processes, and indicator-based management has progressively modified the conditions under which academic work is carried out, incorporating new responsibilities related to the documentation of activities, monitoring of outcomes, and participation in institutional processes, thereby laying the groundwork for analyzing accreditation as an organizational demand.

From this perspective, universities can be analyzed as complex work systems in which academic activities are interconnected with broader organizational processes.

The everyday functioning of these institutions depends on the interaction among administrative structures, institutional policies, available resources, and coordination dynamics among different actors.

3.3 Institutional evaluation and the configuration of academic work

Within the context of contemporary higher education policies, systems of institutional evaluation and accreditation have acquired a central role in the regulation and management of universities. These mechanisms involve a series of organizational activities that influence the internal dynamics of institutions.

Accreditation processes usually involve activities or tasks that require the participation of various institutional actors, particularly faculty members, who contribute to the generation and organization of the information required for evaluation processes.

From the perspective of organizational ergonomics, these dynamics can be understood as part of the academic work system, as they influence the way responsibilities are distributed within educational programs, the coordination processes among institutional actors, and the organization of various activities related to academic management.

4. METHODOLOGY

4.1 Study design

A descriptive quantitative study was conducted to analyze faculty perceptions of accreditation and its relationship with the organization of academic work. This design makes it possible to explore general trends in faculty experiences with institutional evaluation processes.

The approach adopted is framed within an organizational analysis in which accreditation processes are considered part of the institutional dynamics that structure the functioning of academic programs. From this perspective, the focus of the study lies in understanding how these processes are perceived by faculty members and how they are integrated into the organization of academic work within the university.

The research was conducted at the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH), a public higher education institution that regularly participates in institutional evaluation and program accreditation processes, during October 2025..

4.2 Participants

The study population consisted of faculty members from different academic units of UMSNH. A probabilistic sampling approach based on voluntary participation was used, targeting faculty who had some degree of involvement or contact with institutional evaluation or academic program accreditation processes.

A total of 283 valid responses were obtained from faculty with different levels of seniority, academic ranks, and types of employment contracts. This diversity made it possible to incorporate perceptions from different disciplinary and organizational contexts within the institution.

The survey included basic sociodemographic variables such as gender, age, years of service, type of employment contract, academic rank, and institutional affiliation, as well as questions related to the faculty's previous participation in accreditation processes.

4.3 Instrument

A structured Likert-type questionnaire consisting of 20 items was designed to collect information. The instrument aimed to explore different dimensions related to faculty perceptions of academic program accreditation processes. To assess the internal consistency of the instrument, Cronbach's alpha coefficient was calculated, obtaining a value of 0.89.

The instrument was organized into five analytical dimensions:

1. Understanding of accreditation
2. Teaching practice and institutional resources
3. Well-being and academic climate
4. Impact on learning
5. Perceived value and critical perspective

In addition, the questionnaire included two open-ended questions aimed at gathering faculty opinions regarding:

- The positive aspects of accreditation processes
- The challenges or areas for improvement that could strengthen their usefulness in teaching practice

The inclusion of these questions made it possible to complement the quantitative information with qualitative observations derived from the direct experiences of faculty members.

4.4 Data collection procedure

The survey was administered through an online questionnaire (Google Forms), which facilitated the participation of faculty members from different academic units of the university.

Before participation, respondents were informed about the objectives of the study and their informed consent was obtained. Participation was voluntary and anonymous, and confidentiality was guaranteed. The data were used exclusively for academic purposes.

4.5 Data analysis strategy

The data obtained through the questionnaire were analyzed using descriptive statistics in order to identify general trends in faculty perceptions regarding accreditation processes. Frequencies and response distributions were calculated for

each item of the instrument, as well as average scores for each dimension based on the aggregation of items.

In the case of the open-ended questions, responses were reviewed through a categorical analysis process, which made it possible to identify recurring patterns in faculty opinions regarding both the positive aspects and the challenges associated with accreditation processes.

This analytical approach made it possible to integrate quantitative and qualitative information to better understand how institutional evaluation processes are perceived by faculty members and how they relate to the organization of academic work within the institution.

5. RESULTS

The analysis of the information obtained makes it possible to identify different patterns in the way faculty perceive accreditation processes within the institutional dynamics of the university.

One of the clearest findings of the study is that faculty members report a relatively high level of general understanding of the objectives of accreditation. The average score for this dimension reached 58.7%, the highest value among the indicators analyzed. This result suggests that institutional evaluation processes have become embedded in the organizational language of universities, particularly in aspects related to academic planning, curriculum review, and the systematization of educational processes.

Open-ended responses reinforce this interpretation. Several participants indicated that accreditation has contributed to updating curricula, improving laboratories, and reviewing academic content, reflecting the perception that these processes can strengthen the academic organization of educational programs. For example, responses such as “updating study plans” or “improving laboratories and updating content” show that part of the faculty associates accreditation with institutional processes of improvement.

However, when the analysis shifts toward the broader organizational effects of accreditation, evaluations become considerably more moderate. Indicators related to teaching practice and resources (37.8%) and well-being and academic climate (36.4%) show the lowest levels of evaluation. This suggests that, from the faculty perspective, accreditation processes do not always translate into visible improvements in the conditions under which academic work is carried out.

In the open-ended responses, this tension appears clearly. Faculty members describe an administrative workload associated with evidence and reporting requirements and perceive a strong emphasis on formal compliance. In this sense, several participants noted that these processes often focus on meeting formal requirements, which may create the perception that accreditation responds more to bureaucratic dynamics than to substantive processes of educational improvement.

Another aspect that emerges from the responses relates to the distribution of academic work during accreditation processes. Some faculty members indicated that the tasks associated with these processes tend to concentrate within a small

group of professors who assume responsibilities related to report preparation, information systematization, and coordination of institutional activities. This situation may generate perceptions of inequality in the distribution of workloads within educational programs.

On the other hand, the dimension related to impact on learning obtained an average of 40.9%, reflecting a moderate evaluation of the ability of accreditation processes to directly influence teaching practices or the educational experience of students.

Although some faculty members acknowledge that these processes may contribute to reviewing graduate profiles or improving curriculum organization, the responses do not suggest a broad consensus regarding their direct impact on classroom dynamics.

Finally, the indicator related to perceived value and critical perspective on accreditation reached an average of 48.4%, reflecting an intermediate position between institutional recognition and organizational questioning. While some participants highlight that accreditation can strengthen the credibility of academic programs or promote continuous improvement processes, others emphasize the need to reconsider the way these mechanisms are implemented within institutions.

Overall, the results suggest that accreditation processes are recognized by faculty as relevant instruments for the evaluation of educational programs; however, they also reveal tensions related to the way these processes are integrated into the everyday dynamics of academic work. From the perspective of organizational ergonomics, these perceptions make it possible to identify a potential gap between the formal design of institutional evaluation systems and the actual conditions under which academic activities are carried out within the university.

6. DISCUSSION

6.1 Accreditation as a component of organizational design

The results make it possible to analyze accreditation not only as a quality evaluation mechanism but also as an institutional practice that reconfigures the organization of academic work (tasks, coordination, and responsibilities) within educational programs.

The high level of understanding observed among faculty suggests the institutionalization of evaluation processes, particularly in aspects related to curriculum updating, the systematization of academic information, and institutional planning.

From the perspective of organizational ergonomics, this phenomenon can be interpreted as part of the evolution of universities toward management models increasingly structured around processes of evaluation and institutional monitoring. In this sense, accreditation systems not only fulfill an evaluative function but also participate in shaping the organizational procedures that guide the functioning of academic programs.

6.2 Tensions between institutional evaluation and organizational conditions

Although accreditation processes are recognized by faculty as relevant mechanisms for evaluating educational programs, the lower evaluations associated with resources and well-being indicate tensions related to the way these processes are integrated into the everyday dynamics of academic work.

The dimensions related to institutional resources, well-being, and academic climate present considerably lower evaluations than those associated with the general understanding of accreditation. This contrast suggests that, although faculty recognize the institutional importance of these mechanisms, they do not necessarily perceive that their implementation translates into substantive improvements in the conditions under which academic work is carried out.

From the perspective of organizational ergonomics, this situation reflects a potential misalignment between the organizational demands generated by evaluation systems and the resources available within the academic work system. Dul and Neumann (2009) point out that the efficient functioning of sociotechnical systems depends on the coherence between organizational tasks, the availability of resources, and the conditions under which individuals perform their work.

In the case of higher education institutions, accreditation processes involve activities such as report preparation and evidence collection—tasks that require time, institutional coordination, and active faculty participation. When these activities are incorporated into academic work without an explicit reconfiguration of organizational resources, they may generate tensions in task distribution and influence faculty perceptions regarding the usefulness of these processes.

6.3 Implications for the sustainability of academic work

The results of the study allow for reflection on the organizational implications that institutional evaluation systems may have for the sustainability of academic work within universities. In recent decades, several studies have indicated that academic work has undergone significant transformations as a result of the expansion of evaluation mechanisms, accountability processes, and indicator-based management (Enders & de Weert, 2009).

Within this context, universities have incorporated new organizational dynamics that expand faculty responsibilities, particularly in relation to the management of institutional information, participation in evaluation processes, and the coordination of academic activities linked to quality assurance systems.

From an organizational ergonomics perspective, considering higher education institutions as complex work systems makes it possible to identify how evaluation policies, academic management mechanisms, and organizational dynamics interact to shape the conditions under which teaching activities are carried out.

In the Mexican context, this reflection becomes particularly relevant following the enactment of the General Law of Higher Education (LGES) and the development of the Higher Education Evaluation and Accreditation System (SEAES), which promote a more comprehensive vision of educational quality. The approach proposed by SEAES recognizes that the evaluation of higher education should consider not only

academic outcomes but also the institutional conditions under which the core functions of universities are carried out (SEAES, 2023).

From this perspective, incorporating ergonomic criteria into the analysis of evaluation systems may contribute to the design of university policies that are more consistent with the organizational realities of institutions. Analyzing accreditation processes as part of the academic work system makes it possible to move toward evaluation models that simultaneously consider educational quality standards and the conditions under which faculty carry out their professional activities.

7. CONCLUSIONS

This study, based on empirical research conducted with faculty members at the Universidad Michoacana de San Nicolás de Hidalgo, shows that accreditation processes are recognized by faculty as relevant mechanisms for strengthening the academic organization of educational programs. In particular, contributions are identified in areas such as curriculum updating, the systematization of academic information, and institutional planning. These elements indicate that quality assurance systems have become meaningfully incorporated into the organizational dynamics of higher education institutions.

However, the analysis also reveals tensions related to the way these processes are integrated into the everyday organization of academic work. Although faculty members report a relatively high level of understanding of the objectives of accreditation, their perceptions of its impact on working conditions, the availability of institutional resources, and the academic climate are considerably more moderate. This situation suggests the existence of a gap between the formal design of institutional evaluation systems and the organizational conditions under which these processes are implemented within universities.

From the perspective of organizational ergonomics, accreditation can be understood as a component of the academic work system that redistributes tasks, coordination processes, and workloads.

The study proposes analyzing accreditation systems both as tools for evaluating educational quality and as institutional mechanisms that influence the organization of academic work and the conditions under which faculty carry out their activities.

Furthermore, the results suggest that the design of university policies aimed at quality assurance could benefit from incorporating criteria related to the organization of work. In the Mexican context—where the General Law of Higher Education (LGES) and the Higher Education Evaluation and Accreditation System (SEAES) promote a broader vision of educational quality—considering the organizational dimension of university work may contribute to the development of evaluation systems that are more consistent with the operational realities of higher education institutions.

Finally, this chapter opens avenues for further research on how to design quality assurance policies that integrate organizational and ergonomic criteria (task distribution, time allocation, and resources) in order to avoid unnecessary tensions in the functioning of universities.

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WORK POSTURES EVALUATION IN A RETAIL STORE

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Resumen: La evaluación ergonómica de los puestos de trabajo es un componente fundamental para identificar factores de riesgos asociados a trastornos musculoesqueléticos y proponer mejoras que favorezcan la salud y la seguridad de los trabajadores. Entre los métodos más utilizados para este propósito se encuentran el Rapid Upper Limb Assessment (RULA) y Ovako Working posture Analysis System (OWAS), herramientas que permiten analizar posturas, movimientos y cargas físicas de manera sistemática.

El método RULA se enfoca principalmente en las posturas del cuello, tronco y extremidades superiores, resultando útil en entornos donde predominan tareas repetitivas o mantenidas que involucran a los miembros superiores. Por su parte, el método OWAS permite clasificar las posturas del cuerpo durante el trabajo, identificando aquellas que pueden generar esfuerzos excesivos. (Molina et. al, 2018).

Se visitó el establecimiento, se observaron las actividades que desempeña la trabajadora y los movimientos que realiza; en base a esto, se decidieron las posturas a evaluar y se procedió a aplicar los métodos mencionados.

Con el método RULA se identificó que dos posturas presentaron un nivel de riesgo moderado, mientras que tres posturas obtuvieron puntuaciones críticas, indicando la necesidad de cambios urgentes. Las posturas más riesgosas fueron aquellas que implican brazos elevados por encima del hombro, flexión excesiva del tronco, desviaciones en la muñeca y distribución desigual del peso corporal, especialmente durante el acomodo de estanterías altas y actividades de inventario. Se debe considerar ampliar el estudio y seguir analizando, monitorear las actividades y posturas que realiza la trabajadora y determinar medidas correctivas, así como reducir los riesgos físicos existentes.

Por otro lado, los resultados del método OWAS mostraron que la mayoría de las posturas se clasificaron como normales y sin efectos dañinos; sin embargo, se identificaron posturas con riesgo moderado y alto, principalmente relacionados con flexión de la espalda, brazos elevados y piernas flexionadas. El análisis de la frecuencia relativa evidenció que permanecer de pie durante largos periodos y adoptar posturas inclinadas representa un riesgo acumulativo para el sistema musculoesquelético.

Palabras claves: Posturas, RULA, OWAS, lesiones.

Relevancia para la ergonomía: Aplicar los métodos RULA y OWAS en el puesto de cajera contribuye al mejoramiento de la ergonomía dentro del área de trabajo y reducción de fatiga. Esto se ve reflejado en una atención al cliente más rápida, eficiente y cordial, pues el trabajador o trabajadora, puede desempeñar sus actividades con mayor comodidad y menos dolor o molestias.

Abstract: Ergonomic assessment of workstations is a fundamental component for identifying risk factors associated with musculoskeletal disorders and proposing improvements that promote the health and safety of workers. Among the most widely used methods for this purpose are the Rapid Upper Limb Assessment (RULA) and the Ovako Working Posture Analysis System (OWAS), tools that allow for the systematic analysis of postures, movements, and physical loads.

The RULA method focuses primarily on postures of the neck, trunk, and upper extremities, proving useful in environments where repetitive or sustained tasks involving the upper limbs predominate. The OWAS method, on the other hand, allows for the classification of body postures during work, identifying those that may generate excessive effort. Molina, R., Galarza, I., Villegas, C., & López, P. (2018).

The establishment was visited, the activities performed by the worker and the movements she makes were observed; based on this, the postures to be evaluated were decided and the methods mentioned were applied.

The RULA method identified two postures as presenting a moderate level of risk, while three postures obtained critical scores, indicating the need for urgent changes. The riskiest postures were those involving arms raised above shoulder level, excessive trunk flexion, wrist deviations, and uneven distribution of body weight, especially during the arrangement of high shelves and inventory activities. Consideration should be given to expanding the study and continuing to analyze and monitor the activities and postures performed by the worker, determine corrective measures, and reduce existing physical risks.

On the other hand, the OWAS method results showed that most postures were classified as normal and without harmful effects; however, postures with moderate and high risk were identified, mainly related to back flexion, raised arms, and flexed legs. The relative frequency analysis showed that standing for long periods and adopting bent postures represents a cumulative risk to the musculoskeletal system.

Keywords: Postures, RULA, OWAS, injuries

Relevance to Ergonomics: Applying the RULA and OWAS methods to the cashier position contributes to improved ergonomics in the workplace and reduced fatigue. This results in faster, more efficient, and more friendly customer service, as the employees can perform their duties more comfortably and with less pain or discomfort.

1. INTRODUCTION

In many companies, workers perform tasks that require maintaining awkward postures, lifting heavy loads, or repetitive movements. These conditions can cause muscle pain, fatigue, and, in the long term, musculoskeletal disorders that affect both the health of the workers and the productivity of the company.

Ergonomic assessment of workstations is a fundamental component for identifying risk factors associated with musculoskeletal disorders and proposing improvements that promote the health and safety of workers. Among the most widely used methods for this purpose are the Rapid Upper Limb Assessment (RULA) and the Ovako Working Posture Analysis System (OWAS).

The RULA method focuses primarily on neck, trunk, and upper limb postures, making it useful in environments where tasks involving the upper limbs predominate. The OWAS method, on the other hand, allows for the classification of body postures during work, identifying those that may generate excessive strain.

The position held by the employee being evaluated is primarily that of cashier in a department store, working Monday through Saturday from 3-8 pm. Her duties include customer service, inventory counting, and cleaning and organizing merchandise.

2. OBJECTIVES

General Objective:

To evaluate the employee's work area by applying postural assessment methods such as OWAS and RULA, in order to identify musculoskeletal risk factors and propose improvement actions that promote health, safety, and efficiency in the workplace.

Specific Objectives:

- To detect postures, positions, and movements that represent exposure to physical risks.
- To apply the OWAS and RULA methods to identify and classify the level of ergonomic risk.
- To conduct systematic sampling during the workday to obtain representative information.
- To determine areas for improvement and propose preventive or corrective actions that reduce exposure to risks.

3. METHODOLOGY

3.1 Observation.

The establishment was visited, and the worker's activities and movements were observed. Based on this, the postures to be evaluated were determined. Photographs and videos were taken from different angles to gain a clearer

understanding of the postures adopted, and the methods were then applied. For the application of the RULA method, the "ruler" from Ergonautas (Diego-Mas, n.d.-b) was used to measure angles in photographs and thus calculate the score for each posture.

3.2 Application of the RULA method.

Posture 1: Bag sold merchandise

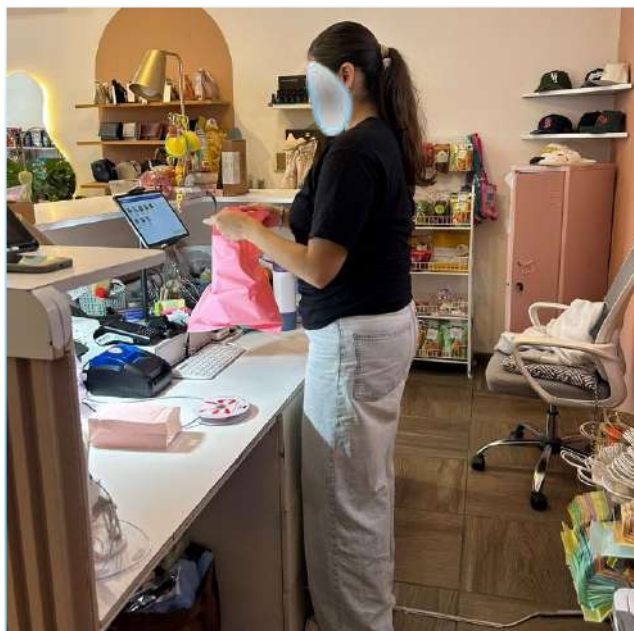


Figure 1. Posture 1

Group A Assessment:

1. Arm Score

The score is 1, as the posture is within 20° of flexion (16°).



Figure 2. Arm assessment in posture 1

2. Forearm score

The score is 2, as the forearm flexion is $>100^\circ$ (102°).



Figure 3. Forearm posture assessment 1

3. Wrist score

The score is 3, as the wrist is flexed or extended $>15^\circ$ (27°).

And the wrist rotation score is 1 because the wrist is in mid-pronation or supination.



Figure 4. Wrist posture assessment 1

Group B Assessment:

1. Neck Score

The score is 3, as the neck posture have a flexion $>20^\circ$ (28°)



Figure 5. Neck posture assessment 1

2. Trunk score

The score is 1, as the worker is standing without any trunk inclination.



Figure 6. Trunk posture assessment 1

3. Leg score

The score is 1, as the worker is standing with her weight symmetrically distributed and has space to change position.



Figure 7. Leg posture assessment 1

Table 1. Level of action

Score	Level	Performance
1 o 2	1	Acceptable risk
3 o 4	2	Changes to the task may be required; further study is advisable
5 o 6	3	Task redesign is required
7	4	Urgent changes to the task are required

The total score for this posture is: 3

Therefore, it is within level 2, which indicates that changes to the task may be required and therefore it is advisable to delve deeper into the study in search of improvements and to try to be within level 1 when applying the improvements.

Método R.U.L.A. Hoja de Campo

A. Análisis de brazo, antebrazo y muñeca

Paso 1: Localizar la posición del brazo

Puntuación brazo = 1

Paso 2: Localizar la posición del antebrazo

Puntuación antebrazo = 2

Paso 3: Localizar la posición de la muñeca

Puntuación muñeca = 3

Paso 4: Giro de muñeca

Puntuación giro de muñeca = 1

Paso 5: Localizar puntuación postural en Tabla A

Utilizar valores de pasos 1, 2, 3 y 4 para localizar puntuación postural en Tabla A

Puntuación postural A = 0

Paso 6: Añadir puntuación utilización muscular

Si la postura es principalmente estática (p.e. agarrar superior a 1 min.) ó si sucede repetidamente la acción (4 veces/min. ó más): +1

Puntuación uso muscular = 0

Paso 7: Añadir puntuación de la Fuerza / Carga

Si carga ó esfuerzo < 2 Kg. intermitente: +0
Si es de 2 a 10 Kg. estática o repetitiva: +2
Si es una carga > 10 Kg. ó vibrante ó súbita: +3

Puntuación fuerza/carga = 0

Paso 8: Localizar fila en Tabla C

Ingresar a Tabla C con la suma de los pasos 5, 6 y 7

Puntuación final muñeca, antebrazo y brazo = 3

B. Análisis de cuello, tronco y pierna

Paso 9: Localizar la posición del cuello

Puntuación cuello = 3

Paso 10: Localizar la posición del tronco

Puntuación tronco = 1

Paso 11: Si hay torsión +1; si hay inclinación lateral: +1

Puntuación piernas = 1

Paso 12: Localizar puntuación postural en Tabla B

Utilizar valores de pasos 9, 10 y 11 para localizar puntuación postural en Tabla B

Puntuación postural B = 3

Paso 13: Añadir puntuación utilización muscular

Si la postura es principalmente estática (p.e. agarrar superior a 1 min.) ó si sucede repetidamente la acción (4 veces/min. ó más): +1

Puntuación uso muscular = 0

Paso 14: Añadir puntuación de la Fuerza / Carga

Si carga ó esfuerzo < 2 Kg. intermitente: +0
Si es de 2 a 10 Kg. estática o repetitiva: +1
Si es de 2 a 10 Kg. estática o repetitiva: +2
Si es una carga > 10 Kg. ó vibrante ó súbita: +3

Puntuación fuerza/carga = 0

Paso 15: Localizar columna en Tabla C

Ingresar a Tabla C con la suma de los pasos 12, 13 y 14

Puntuación final cuello, antebrazo y brazo = 3

Referencias:

Observador: _____ Firma: _____

Puntuación Final: 1 ó 2: Aceptable; 3 ó 4: Ampliar el estudio; 5 ó 6: Ampliar el estudio y modificar pronto; 7: estudiar y modificar inmediatamente

Figure 8. Field sheet Rula posture 1

Posture 2: Merchandise arrangement (lenses)



Figure 9. Posture 2

Group A Assessment:

1. Arm Score

The score is 2, as the posture shows flexion greater than 20° (30°).



Figure 10. Arm posture assessment 2

2. Forearm score

The score is 1, as the forearm flexion is between 60° and 100° (90°).



Figure 11. Forearm posture assessment 2

3. Wrist Score

The score is 2, as the wrist is within flexion or extension $>0^\circ$ and $<15^\circ$ (7°). Since present extreme pronation or supination, the wrist rotation score is 2. Because the activity is primarily static (performed more than 4 times per minute when arranging merchandise upon arrival), we add +1 after locating your data in Table A, due to muscle utilization.



Figure 12. Wrist posture assessment 2

Group B Assessment:

1. Neck Score

The score is 2, as it presents a flexion $\leq 20^\circ$ (20°).



Figure 13. Neck posture assessment 2

2. Trunk score

The score is 1, as the worker is standing without any trunk inclination.



Figure 14. Trunk posture assessment 2

3. Leg Score

Their score is 1, as the worker stands with their weight symmetrically distributed and has space to change position.

Since the activity is primarily static (performed for more than a minute while arranging merchandise upon arrival), we added +1 after locating our data in Table B, due to muscle use.



Figure 15. Leg posture assessment 2

Método R.U.L.A. Hoja de Campo

A. Análisis de brazo, antebrazo y muñeca

Paso 1: Localizar la posición del brazo

Si el hombro está elevado +1
Si el brazo está abducido (despegado del cuerpo): +1
Si el brazo está apoyado o sostenido: -1

Puntuación brazo

Paso 2: Localizar la posición del antebrazo

Si el antebrazo está elevado +1
Si el antebrazo está en posición neutra: 0
Si el antebrazo está en posición flexionada: +1

Puntuación antebrazo

Paso 3: Localizar la posición de la muñeca

Si la muñeca está en posición neutra: 0
Si la muñeca está en posición flexionada: +1
Si la muñeca está en posición extendida: +1

Puntuación muñeca

Paso 4: Giro de muñeca

Si la muñeca está en el rango medio de giro: +1
Si la muñeca está girada próxima al rango final de giro: +2

Puntuación giro de muñeca

Paso 5: Localizar puntuación postural en Tabla A

Utilizar valores de pasos 1, 2, 3 y 4 para localizar puntuación postural en Tabla A

Puntuación postural A

Paso 6: Añadir puntuación utilización muscular

Si la postura es principalmente estática (p.e. agarres superiores a 1 min.) ó si sucede repetidamente la acción (4 veces/mín. ó más): +1

Puntuación uso muscular

Paso 7: Añadir puntuación de la Fuerza / Carga

Si carga o esfuerzo < 2 Kg. intermitente: +1
Si es de 2 a 10 Kg. estática o repetitiva: +2
Si es una carga > 10 Kg. ó vibrante ó súbita: +3

Puntuación fuerza/carga

Paso 8: Localizar fila en Tabla C

Ingresar a Tabla C con la suma de los pasos 5, 6 y 7

Puntuación final muñeca, antebrazo y brazo

B. Análisis de cuello, tronco y pierna

Paso 9: Localizar la posición del cuello

Si el cuello está en posición neutra: 0
Si el cuello está en posición flexionada: +1
Si el cuello está en posición extendida: +1

Puntuación cuello

Paso 10: Localizar la posición del tronco

Si el tronco está en posición neutra: 0
Si el tronco está en posición flexionada: +1
Si el tronco está en posición extendida: +1

Puntuación tronco

Paso 11: Localizar puntuación postural en Tabla B

Utilizar valores de pasos 9, 10 y 11 para localizar puntuación postural en Tabla B

Puntuación postural B

Paso 12: Añadir puntuación utilización muscular

Si la postura es principalmente estática (p.e. agarres superiores a 1 min.) ó si sucede repetidamente la acción (4 veces/mín. ó más): +1

Puntuación uso muscular

Paso 13: Añadir puntuación de la Fuerza / Carga

Si carga o esfuerzo < 2 Kg. intermitente: +1
Si es de 2 a 10 Kg. estática o repetitiva: +2
Si es una carga > 10 Kg. ó vibrante ó súbita: +3

Puntuación fuerza/carga

Paso 14: Localizar columna en Tabla C

Ingresar a Tabla C con la suma de los pasos 12, 13 y 14

Puntuación final cuello, antebrazo y brazo

Referencias:

Observador:

Fecha:

Puntuación Final: 1 ó 2: Aceptable; 3 ó 4: Ampliar el estudio; 5 ó 6: Ampliar el estudio y modificar pronto; 7: estudiar y modificar inmediatamente

Figure 16. Rula Posture field sheet 2

The total score for this posture is: 3

Therefore, it falls within level 2, which indicates that changes to the task may be required and therefore further study is advisable.

Posture 3: Arrangement of merchandise (lenses) on top of shelf



Figure 17. Posture 3

Group A Assessment:**1. Arm Score**

The score is 4, as it shows flexion $>90^\circ$ (110°).

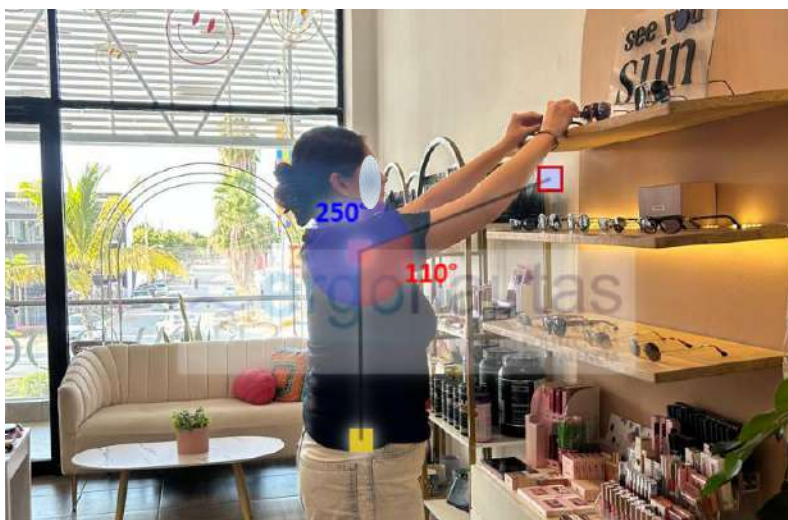


Figure 18. Arm posture assessment 3

2. Forearm score

The score is 2, as it presents a flexion $<60^\circ$ (16°).



Figure 19. Forearm posture assessment 3

3. Wrist score

The score is 4, as it shows flexion $>15^\circ$ (16°), which gives us a score of 3, and we add +1 because it shows radial deviation.

The wrist rotation score is 2, as it shows extreme pronation or supination.



Figure 20. Wrist posture assessment 3

Group B Assessment:

1. Neck Score

The score is 4, as it shows an extension greater than 0° (26°).

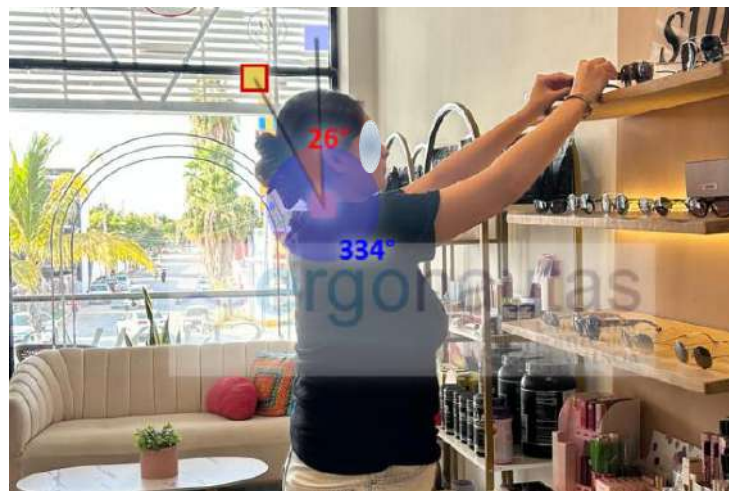


Figure 21. Neck posture assessment 3

2. Trunk assessment

Its score is 1, since the worker is standing upright without flexion or extension.

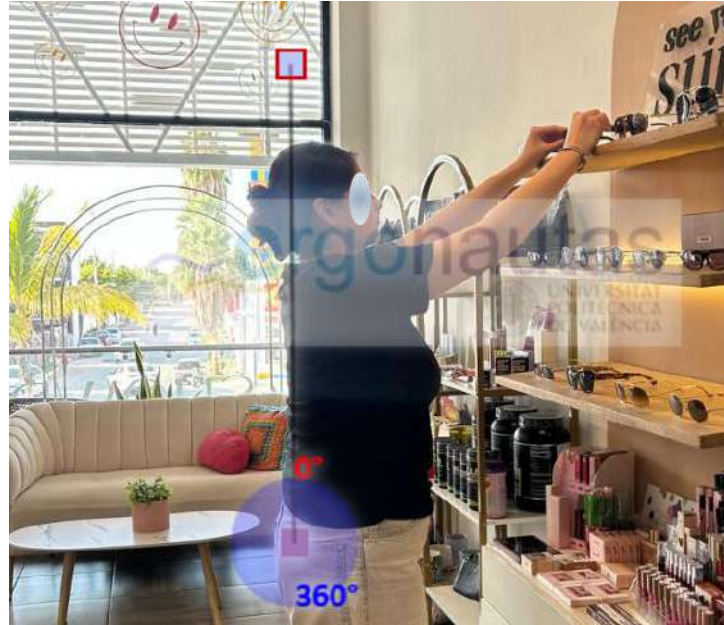


Figure 22. Trunk posture assessment 3

3. Leg Assessment

Their score is 1, as the worker is standing with her weight symmetrically distributed and has space to change position. Since the activity is primarily static (performed for more than a minute when arranging merchandise upon arrival), we added +1 after locating our data in Table B, due to muscle use.



Figure 23. Leg posture assessment 3

Método R.U.L.A. Hoja de Campo

A. Análisis de brazo, antebrazo y muñeca

Paso 1: Localizar la posición del brazo

+1: -20° a -20°
 +2: -20° a -20°
 +3: 20° a 45°
 +4: 45° a 90°
 Si el brazo está abducido (desapoyado del cuerpo): +1
 Si el brazo está apoyado o sostenido: -1

Puntuación brazo = 4

Paso 2: Localizar la posición del antebrazo

+1: 60° a 120°
 +2: 0° a 60°
 +3: 120° a 180°
 Si el brazo cruza la línea media del cuerpo: +1
 Si el brazo sale de la línea del cuerpo: +1

Puntuación antebrazo = 2

Paso 3: Localizar la posición de la muñeca

+1: 0° a 15°
 +2: 15° a 30°
 +3: 30° a 45°
 +4: 45° a 60°
 Si la muñeca está doblada por la línea media: +1

Puntuación muñeca = 4

Paso 4: Giro de muñeca

+1: Si la muñeca está en el rango medio de giro
 +2: Si la muñeca está girada próximo al rango final de giro

Puntuación giro de muñeca = 2

Paso 5: Localizar puntuación postural en Tabla A

Utilizar valores de pasos 1, 2, 3 y 4 para localizar puntuación postural en Tabla A

Puntuación postural A = 5

Paso 6: Añadir puntuación utilización muscular

Si la postura es principalmente estática (p.e., aperturas superiores a 1 min.) ó si sucede repetidamente la acción (4 veces/min. ó más): +1

Puntuación uso muscular = 1

Paso 7: Añadir puntuación de la Fuerza / Carga

Si carga o esfuerzo < 2 Kg. intermitente: +0
 Si es de 2 a 10 Kg. intermitente: +1
 Si es de 2 a 10 Kg. estática o repetitiva: +2
 Si es una carga > 10 Kg. ó vibrante ó súbita: +3

Puntuación fuerza/carga = 0

Paso 8: Localizar fila en Tabla C

Ingresar a Tabla C con la suma de los pasos 5, 6 y 7

Puntuación final muñeca, antebrazo y brazo = 6

B. Análisis de cuello, tronco y pierna

Paso 9: Localizar la posición del cuello

+1: 0° a 15°
 +2: 15° a 30°
 +3: 30° a 45°
 +4: 45° a 60°
 Si hay rotación: +1; si hay inclinación lateral: +1
 Si hay extensión, cualquier ángulo

Puntuación cuello = 4

Paso 10: Localizar la posición del tronco

+1: sentado 0° a 15°
 +2: 15° a 30°
 +3: 30° a 45°
 +4: 45° a 60°
 Si hay torsión: +1; si hay inclinación lateral: +1

Puntuación tronco = 1

Paso 11: Localizar la posición de la pierna

+1: Si piernas y pies apoyados y equilibrados
 +2: Si no

Puntuación piernas = 1

Tabla A

Brazo	Antebrazo	Muñeca	1	2	3	4
1	1	1	1	2	3	4
2	2	2	2	3	4	5
3	3	3	3	4	5	6
4	4	4	4	5	6	7
5	5	5	5	6	7	8
6	6	6	6	7	8	9
7	7	7	7	8	9	10
8	8	8	8	9	10	11
9	9	9	9	10	11	12
10	10	10	10	11	12	13
11	11	11	11	12	13	14
12	12	12	12	13	14	15
13	13	13	13	14	15	16
14	14	14	14	15	16	17
15	15	15	15	16	17	18
16	16	16	16	17	18	19
17	17	17	17	18	19	20
18	18	18	18	19	20	21
19	19	19	19	20	21	22
20	20	20	20	21	22	23
21	21	21	21	22	23	24
22	22	22	22	23	24	25
23	23	23	23	24	25	26
24	24	24	24	25	26	27
25	25	25	25	26	27	28
26	26	26	26	27	28	29
27	27	27	27	28	29	30
28	28	28	28	29	30	31
29	29	29	29	30	31	32
30	30	30	30	31	32	33
31	31	31	31	32	33	34
32	32	32	32	33	34	35
33	33	33	33	34	35	36
34	34	34	34	35	36	37
35	35	35	35	36	37	38
36	36	36	36	37	38	39
37	37	37	37	38	39	40
38	38	38	38	39	40	41
39	39	39	39	40	41	42
40	40	40	40	41	42	43
41	41	41	41	42	43	44
42	42	42	42	43	44	45
43	43	43	43	44	45	46
44	44	44	44	45	46	47
45	45	45	45	46	47	48
46	46	46	46	47	48	49
47	47	47	47	48	49	50
48	48	48	48	49	50	51
49	49	49	49	50	51	52
50	50	50	50	51	52	53
51	51	51	51	52	53	54
52	52	52	52	53	54	55
53	53	53	53	54	55	56
54	54	54	54	55	56	57
55	55	55	55	56	57	58
56	56	56	56	57	58	59
57	57	57	57	58	59	60
58	58	58	58	59	60	61
59	59	59	59	60	61	62
60	60	60	60	61	62	63
61	61	61	61	62	63	64
62	62	62	62	63	64	65
63	63	63	63	64	65	66
64	64	64	64	65	66	67
65	65	65	65	66	67	68
66	66	66	66	67	68	69
67	67	67	67	68	69	70
68	68	68	68	69	70	71
69	69	69	69	70	71	72
70	70	70	70	71	72	73
71	71	71	71	72	73	74
72	72	72	72	73	74	75
73	73	73	73	74	75	76
74	74	74	74	75	76	77
75	75	75	75	76	77	78
76	76	76	76	77	78	79
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78	78	78	78	79	80	81
79	79	79	79	80	81	82
80	80	80	80	81	82	83
81	81	81	81	82	83	84
82	82	82	82	83	84	85
83	83	83	83	84	85	86
84	84	84	84	85	86	87
85	85	85	85	86	87	88
86	86	86	86	87	88	89
87	87	87	87	88	89	90
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89	89	89	89	90	91	92
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91	91	91	91	92	93	94
92	92	92	92	93	94	95
93	93	93	93	94	95	96
94	94	94	94	95	96	97
95	95	95	95	96	97	98
96	96	96	96	97	98	99
97	97	97	97	98	99	100
98	98	98	98	99	100	101
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102	102	102	102	103	104	105
103	103	103	103	104	105	106
104	104	104	104	105	106	107
105	105	105	105	106	107	108
106	106	106	106	107	108	109
107	107	107	107	108	109	110
108	108	108	108	109	110	111
109	109	109	109	110	111	112
110	110	110	110	111	112	113
111	111	111	111	112	113	114
112	112	112	112	113	114	115
113	113	113	113	114	115	116
114	114	114	114	115	116	117
115	115	115	115	116	117	118
116	116	116	116	117	118	119
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119	119	119	119	120	121	122
120	120	120	120	121	122	123
121	121	121	121	122	123	124
122	122	122	122	123	124	125
123	123	123	123	124	125	126
124	124	124	124	125	126	127
125	125	125	125	126	127	128
126	126	126	126	127	128	129
127	127	127	127	128	129	130
128	128	128	128	129	130	131
129	129	129	129	130	131	132
130	130	130	130	131	132	133
131	131	131	131	132	133	134
132	132	132	132	133	134	135
133	133	133	133	134	135	136
134	134	134	134	135	136	137
135	135	135	135	136	137	138
136	136	136	136	137	138	139
137	137	137	137	138	139	140
138	138	138	138	139	140	141
139	139	139	139	140	141	142
140	140	140	140	141	142	143
141	141	141	141	142	143	144
142	142	142	142	143	144	145
143	143	143	143	144	145	146
144	144	144	144	145	146	147
145	145	145	145	146	147	148
146	146	146	146	147	148	149
147	147	147	147	148	149	150
148	148	148	148	149	150	151
149	149	149	149	150	151	152
150	150	150	150	151	152	153
151	151	151	151	152	153	154
152	152	152	152	153	154	155
153	153	153	153	154	155	156
154	154	154	154	155	156	157
155	155	155	155	156	157	158
156	156	156	156	157	158	159
157	157	157	157	158	159	160
158	158	158	158	159	160	161
159	159	159	159	160	161	162
160	160	160	160	161	162	163
161	161	161	161	162	163	164
162	162	162	162	163	164	165
163	163	163	163	164	165	166
164	164	164	164	165	166	167
1						

Group A Assessment:

1. Arm Score

The score is 4, as it shows flexion $>90^\circ$ (93°).



Figure 26. Arm posture assessment 4

2. Forearm score

The score is 2, because it shows flexion $<60^\circ$ (0°).



Figure 27. Forearm posture assessment 4

3. Wrist score

The score is 3, as it shows flexion $>0^\circ$ (9°), which gives us a score of 2; and we add +1 because it shows ulnar deviation.

The wrist rotation score is 2, because we can observe extreme pronation or supination.



Figure 28. Wrist posture assessment 4

Group B Assessment:

1. Neck Score

It has a score of 4, as it presents extension (19°).

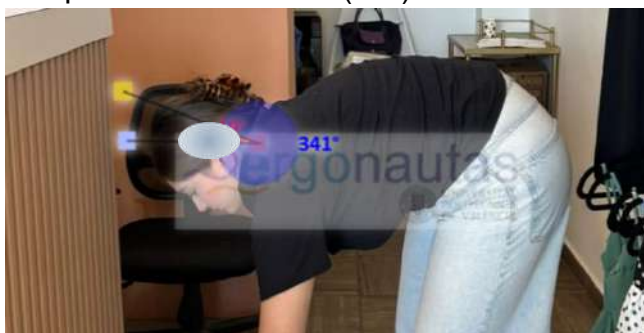


Figure 29. Neck posture assessment 4

2. Trunk score

The score is 4, as it presents flexion $>60^\circ$ (103°).



Figure 30. Trunk posture assessment 4

3. Leg score

The score is 2, as she are standing, but the weight is not symmetrically distributed.



Figure 31. Leg posture assessment 4

Método R.U.L.A. Hoja de Campo

A. Análisis de brazo, antebrazo y muñeca		PUNTAJACIÓN		B. Análisis de cuello, tronco y pierna																																																																																																																																																																																																																																																																																																																																																																													
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Paso 3: Localizar la posición de la muñeca 		Paso 11: 																																																																																																																																																																																																																																																																																																																																																																															
Paso 4: Giro de muñeca 		Paso 12: Localizar puntuación postural en Tabla B Utilizar valores de pasos 9, 10 y 11 para localizar puntuación postural en Tabla B.																																																																																																																																																																																																																																																																																																																																																																															
Paso 5: Localizar puntuación postural en Tabla A Utilizar valores de pasos 1, 2, 3 y 4 para localizar puntuación postural en Tabla A.		Paso 13: Añadir puntuación utilización muscular Si la postura es principalmente estática (p.e. agarres superiores a 1 min.) o si sucede repetidamente la acción (4 veces/mín. o más): +1 Si es una carga >10 Kg. o vibrante o súbita: +2																																																																																																																																																																																																																																																																																																																																																																															
Paso 6: Añadir puntuación utilización muscular Si la postura es principalmente estática (p.e. agarres superiores a 1 min.) o si sucede repetidamente la acción (4 veces/mín. o más): +1 Si es una carga >10 Kg. o vibrante o súbita: +2		Paso 14: Añadir puntuación de la Fuerza / Carga Si carga o esfuerzo < 2 Kg. intermitente: 0 Si es de 2 a 10 Kg. intermitente: +1 Si es de 2 a 10 Kg. estática o repetitiva: +2 Si es una carga >10 Kg. o vibrante o súbita: +3																																																																																																																																																																																																																																																																																																																																																																															
Paso 7: Añadir puntuación de la Fuerza / Carga Si carga o esfuerzo < 2 Kg. intermitente: 0 Si es de 2 a 10 Kg. intermitente: +1 Si es de 2 a 10 Kg. estática o repetitiva: +2 Si es una carga >10 Kg. o vibrante o súbita: +3		Paso 15: Localizar columna en Tabla C Ingresar a Tabla C con la suma de los pasos 5, 6 y 7.																																																																																																																																																																																																																																																																																																																																																																															
Paso 8: Localizar fila en Tabla C Ingresar a Tabla C con la suma de los pasos 5, 6 y 7.		Referencias: Observador: _____ Firma: _____																																																																																																																																																																																																																																																																																																																																																																															
Puntuación final: 1 a 2: Aceptable; 3 a 4: Ampliar el estudio; 5 a 6: Ampliar el estudio y modificar pronto; 7: estudiar y modificar inmediatamente		Puntuación final: 1 a 2: Aceptable; 3 a 4: Ampliar el estudio; 5 a 6: Ampliar el estudio y modificar pronto; 7: estudiar y modificar inmediatamente																																																																																																																																																																																																																																																																																																																																																																															

Figure 32. Rula Posture 4 field sheet

The total score for this posture is: 7

Therefore, it falls within level 4, which indicates that urgent changes to the task are required, as it is considered a critical posture that may affect the worker.

Posture 5: Counting sportswear (inventory)



Figure 33. Posture 5

Group A Assessment:

1. Arm Score

The score is 3, as it has a flexion of less than 90° (67°).



Figure 34. Arm posture assessment 5

2. Forearm score

The score is 2, as it shows a flexion $<60^\circ$ (0°).



Figure 35. Forearm posture assessment 5

3. Wrist score

The final score is 3, as the extension is $> 0^\circ$ and $< 15^\circ$, giving a score of 2; and we add +1 because ulnar deviation is present.

The wrist rotation score is 1, as there is mid-pronation or supination.



Figure 36. Wrist posture assessment 5

Group B Assessment:

1. Neck Score

The score is 1, as it shows 10° flexion (10°).



Figure 37. Neck posture assessment 5

2. Trunk score

The score is 4, because it presents flexion $>60^\circ$ (79°).



Figure 38. Trunk posture assessment 5

3. Leg Score

The score is 2, as her feet are not supported and your weight is not symmetrically distributed.

Since the activity is primarily static (performed for more than a minute while unpacking the merchandise upon arrival), we added +1 after locating your data in Table B, due to the muscle engagement.



Método R.U.L.A. Hoja de Campo

A. Análisis de brazo, antebrazo y muñeca

Paso 1: Localizar la posición del brazo

-20° -20° o +20°
Si el hombro está elevado +1
Si el brazo está abducido (despegado del cuerpo): +1
Si el brazo está apoyado o sostenido: -1

Puntuación brazo = 3

Paso 2: Localizar la posición del antebrazo

0° -100°
+1
+2

Paso 2a: Corregir...
Si el brazo cruza la línea media del cuerpo: +1
Si el brazo sale de la línea media del cuerpo: -1

Puntuación antebrazo = 2

Paso 3: Localizar la posición de la muñeca

0° -15°
+1
+2
+3

Paso 3a: Corregir...
Si la muñeca está doblada por la línea media: +1

Puntuación muñeca = 3

Paso 4: Giro de muñeca

0° -90°
+1
+2

Puntuación giro de muñeca = 1

Paso 5: Localizar puntuación postural en Tabla A

Utilizar valores de pasos 1, 2, 3 y 4 para localizar puntuación postural en Tabla A

Puntuación postural A = 4

Paso 6: Añadir puntuación utilización muscular

Si la postura es principalmente estática (p.e. agarros superiores a 1 min.) o si sucede repetidamente la acción (4 veces/min. o más): +1

Puntuación uso muscular = 1

Paso 7: Añadir puntuación de la Fuerza / Carga

Si carga o esfuerzo < 2 Kg. intermitente: +0
Si es de 2 a 10 Kg. intermitente: +1
Si es de 2 a 10 Kg. estática o repetitiva: +2
Si es una carga > 10 Kg. o vibrante o súbita: +3

Puntuación fuerza/carga = 0

Paso 8: Localizar fila en Tabla C

Ingresar a Tabla C con la suma de los pasos 5, 6 y 7

Puntuación final muñeca, antebrazo y brazo = 5

B. Análisis de cuello, tronco y pierna

Paso 9: Localizar la posición del cuello

0° -10°
+1
+2
+3
+4

Paso 9a: Corregir...
Si hay rotación: +1; Si hay inclinación lateral: +1

Puntuación cuello = 1

Paso 10: Localizar la posición del tronco

0° -20°
+1
+2
+3
+4

Paso 10a: Corregir...
Si hay torsión: +1; Si hay inclinación lateral: +1

Puntuación tronco = 4

Paso 11:

0° -10°
+1
+2
+3
+4

Paso 12: Localizar puntuación postural en Tabla B

Utilizar valores de pasos 9, 10 y 11 para localizar puntuación postural en Tabla B

Puntuación postural B = 5

Paso 13: Añadir puntuación utilización muscular

Si la postura es principalmente estática (p.e. agarros superiores a 1 min.) o si sucede repetidamente la acción (4 veces/min. o más): +1

Puntuación uso muscular = 1

Paso 14: Añadir puntuación de la Fuerza / Carga

Si carga o esfuerzo < 2 Kg. intermitente: +0
Si es de 2 a 10 Kg. intermitente: +1
Si es de 2 a 10 Kg. estática o repetitiva: +2
Si es una carga > 10 Kg. o vibrante o súbita: +3

Puntuación fuerza/carga = 0

Paso 15: Localizar columna en Tabla C

Ingresar a Tabla C con la suma de los pasos 12, 13 y 14

Puntuación final cuello, antebrazo y brazo = 6

7

Puntuación Final: 1 ó 2: Aceptable; 3 ó 4: Ampliar el estudio; 5 ó 6: Ampliar el estudio y modificar pronto; 7: estudiar y modificar inmediatamente

Figure 40. Rula Posture 5 field sheet

The total score for this posture is: 6

Therefore, it falls within level 4, which indicates that urgent changes to the task are required, as it is considered a critical posture that may affect the worker.

3.2 Application of the OWAS method

3.2.1 Risk categories and corrective actions

Posture 1: Packaging of sold merchandise



Figure 41. OWAS Posture 1.

Table 2. Risk Categories Posture 1

Posture 1	Back	Arms	Legs	Load
Code	1	1	2	1
Posture	Straight back	Both arms down	Standing with both legs straight	Less than 10 kg
Risk	1	Normal and natural posture with no harmful effects on the musculoskeletal system.	No action required.	

Table 3. Risk category by posture code 1

Piernas		1			2			3			4			5			6			7		
Carga		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Espalda	Brazos																					
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3
	2	2	2	3	2	2	3	2	3	3	3	4	4	3	4	3	3	3	4	2	3	4
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	2	3	4
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	1	1	1	1
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4
	2	3	3	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4

This posture falls into risk category 1 according to the OWAS method. The posture involves a straight back, arms down, standing with both legs straight, and weighing less than 10 kg. This score of 1 indicates a normal and natural posture with no harmful effects on the musculoskeletal system. This posture requires no action.

Posture 2: Merchandise arrangement (lenses)



Figure 42. OWAS Posture 2.

Table 4. Risk category posture 2

Posture 2	Back	Arms	Legs	Load
Code	1	1	2	1
Posture	Straight back	Both arms down	Standing with both legs straight	Less than 10 kg
Risk	1	Normal and natural posture with no harmful effects on the musculoskeletal system.	No action required.	

Table 5. Risk category by posture code 2

Piernas		1			2			3			4			5			6			7		
Carga		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Espalda		Brazos																				
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3
	2	2	2	3	2	2	3	2	3	3	3	4	4	3	3	3	3	3	4	2	3	4
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	2	3	4
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	4	1	1	1
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4
	2	3	3	4	2	3	4	3	3	3	4	4	4	4	4	4	4	4	4	2	3	4
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4

This posture is in a risk category of 1 according to the OWAS method, with the back straight, arms low, standing with both legs straight and weighing less than 10 kg, thus giving a score of 1 which is a normal and natural posture without harmful effects on the musculoskeletal system.

Posture 3: Arrangement of merchandise (lenses) on top of shelf



Figure 43. Posture 3 OWAS

Table 6. Risk category posture 3

Posture 3	Back	Arms	Legs	Load
Code	1	3	2	1
Posture	Straight back	The two arms raised	Standing with both legs straight	Less than 10 kg
Risk	1	Normal and natural posture with no harmful effects on the musculoskeletal system.	No action required.	

Table 7. Risk category by posture code 3

Piernas		1			2			3			4			5			6			7		
Carga		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Espalda	Brazos																					
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3
	2	2	2	3	2	2	3	2	3	3	3	4	4	3	4	3	3	3	4	2	3	4
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	2	3	4
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	4	1	1	1
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4
	2	3	3	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4

This posture falls into risk category 1 according to the OWAS method. The posture involves a straight back, both arms raised, standing with both legs straight, and weighing less than 10 kg, thus receiving a score of 1. This is a normal and natural posture with no harmful effects on the musculoskeletal system. This posture requires no action.

Posture 4: Leaving a box to count inventory (of sportswear)



Figure 44. OWAS Posture 4

Table 8. Posture risk category 4

Posture 4	Back	Arms	Legs	Load
Code	2	1	2	1
Posture	Bent back	Both arms down	Standing with both legs straight	Less than 10 kg
Risk	2	Posture with the potential to cause damage to the musculoskeletal system	Corrective action is required in the near future	

Table 9. Risk category by posture code 4

Piernas		1			2			3			4			5			6			7		
Carga		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Espalda	Brazos																					
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3
	2	2	2	3	2	2	3	2	3	3	3	3	3	4	4	3	3	3	3	4	2	3
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	2	3	4
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	4	1	1	1
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4
	2	3	3	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4

This posture falls into risk category 2 according to the OWAS method. The posture involves a bent back, both arms lowered, standing with both legs straight, and carrying a load of less than 10 kg. This score of 2 indicates a posture with the potential to cause musculoskeletal damage. Corrective action is required in the near future.

Posture 5: counting sportswear (inventory)



Figure 45. Posture 5 OWAS

Table 10. Posture risk category 5

Posture 5	Back	Arms	Legs	Load
Code	2	1	6	1
Posture	Bent back	Both arms down	Kneeling	Less than 10kg
Risk	2	Posture with the potential to cause damage to the musculoskeletal system	Corrective action is required in the near future	

Table 11. Risk category by posture code 5

Piernas		1			2			3			4			5			6			7		
Carga		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Espalda	Brazos																					
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3
	2	2	2	3	2	2	3	2	3	3	3	4	4	3	4	3	3	3	4	2	3	4
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	2	3	4
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	4	1	1	1
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4
	2	3	3	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4

This posture falls into risk category 2 according to the OWAS method, with the back bent, both arms down, kneeling, and carrying a load of less than 10 kg. This score of 2 indicates a posture with the potential to cause musculoskeletal damage. Corrective action is required in the near future.

3.2.2 Risk category of body parts according to their relative frequency.

Table 12. Back Frequency

Back	Frequency
straight	3
Leaning forward or flexed	2
Rotated or tilted laterally	0
Inclined and turned	0

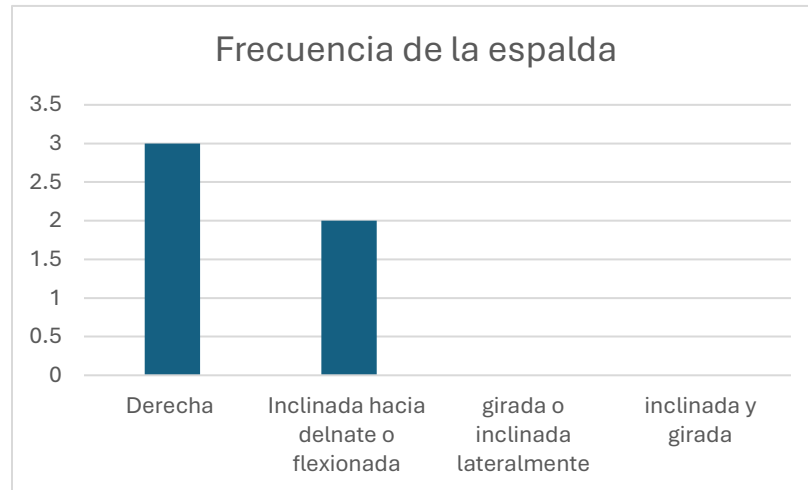


Figure 46. Back Frequency

Table 13. Arm Frequency

Arms	Frequency
Two low arms	4
One arm low and the other raised	0
Two raised arms	1

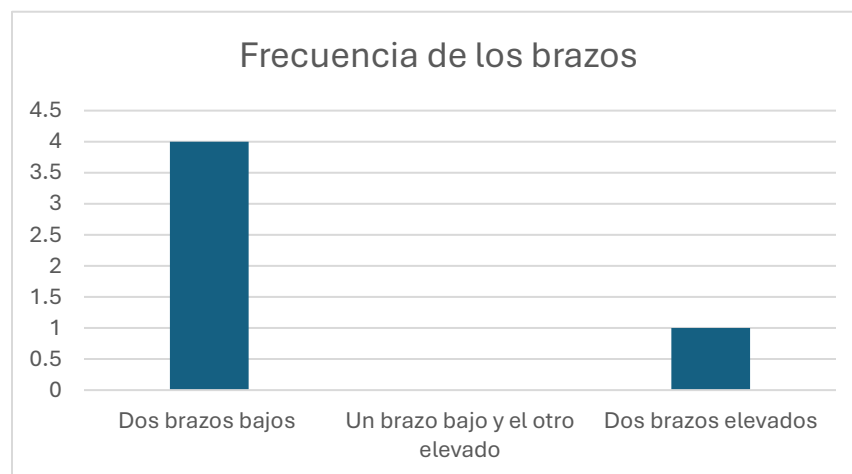


Figure 47. Arm frequency

Table 14. Leg Frequency

Legs	Frequency
Sitting	0
standing	4
On one straight leg	0
On bent knees	0
On one bent knee	0
Kneeling	1
Walking	0

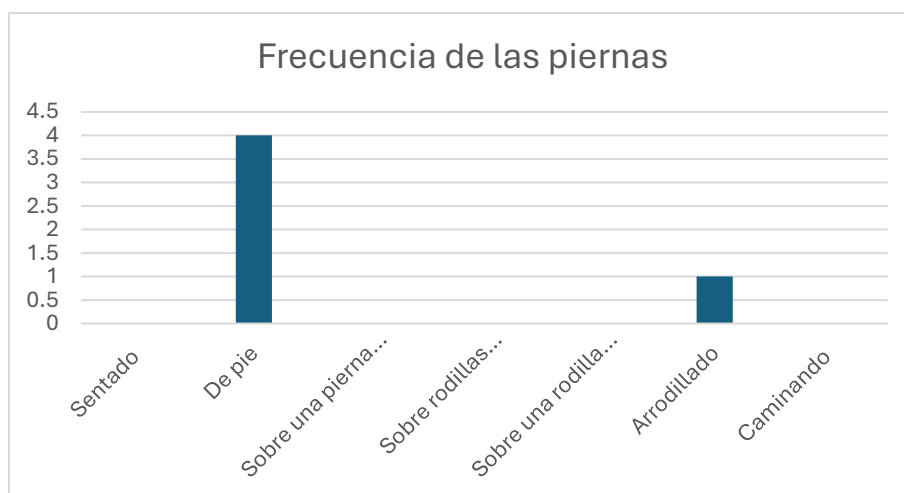


Figure 48. Leg frequency

Table 15. Risk category of body postures according to their relative frequency

Frecuencia Relativa		≤10%	≤20%	≤30%	≤40%	≤50%	≤60%	≤70%	≤80%	≤90%	≤100%
ESPALDA	Derecha	1	1	1	1	1	1	1	1	1	1
	Inclinada hacia adelante o flexionada	1	1	1	2	2	2	2	2	3	3
	Girada o inclinada lateralmente	1	1	2	2	2	3	3	3	3	3
	Inclinada y girada	1	2	2	3	3	3	3	4	4	4
BRAZOS	Dos brazos bajos	1	1	1	1	1	1	1	1	1	1
	Un brazo bajo y el otro elevado	1	1	1	2	2	2	2	2	3	3
	Dos brazos elevados	1	1	2	2	2	2	2	3	3	3
PIERNAS	Sentado	1	1	1	1	1	1	1	1	1	2
	De pie	1	1	1	1	1	1	1	1	2	2
	Sobre una pierna recta	1	1	1	2	2	2	2	2	3	3
	Sobre rodillas flexionadas	1	2	2	3	3	3	3	4	4	4
	Sobre una rodilla flexionada	1	2	2	3	3	3	3	4	4	4
	Arrodillado	1	1	2	2	2	3	3	3	3	3
	Caminando	1	1	1	1	1	1	1	1	2	2

Back

In the back posture assessment, two different postures were identified. The first corresponds to a straight back, which had a relative frequency of 60%, placing it in risk category 1. This indicates that it is a normal and natural posture without harmful effects on the musculoskeletal system.

The second posture corresponds to a forward-leaning and flexed back, which had a relative frequency of 40%. This posture was classified in risk category 2, which implies a risk of causing damage to the musculoskeletal system; therefore, corrective actions are required in the near future.

Arms

In the arm posture assessment, two different postures were identified. The first corresponds to both arms held low, which had a relative frequency of 80%, placing it in risk category 1. This indicates that it is a normal and natural posture without harmful effects on the musculoskeletal system. The second posture, with both arms raised, had a relative frequency of 20%, placing it in risk category 1. This indicates that it is a normal and natural posture without harmful effects on the musculoskeletal system.

Legs

In the leg posture assessment, two different positions were identified. The first was standing, with a relative frequency of 80%, placing it in risk category 1. This indicates that it is a normal and natural posture without harmful effects on the musculoskeletal system.

The second posture was kneeling, with a relative frequency of 20%. This posture was also classified in risk category 1, indicating that it is a normal and natural posture without harmful effects on the musculoskeletal system.

4. RESULTS

4.1 Rula method

Postures 1 (packing sold merchandise) and 2 (arranging merchandise – glasses) scored 3, placing them within level 2 (considered not alarming, but not entirely unnoticeable). Further study of the case is necessary to determine precisely where changes are required. The most concerning aspects were the forearm and wrist angles, which, although close to acceptable or optimal levels, have room for improvement. This would allow the employee to work more efficiently and reduce productivity losses.

In turn, several critical positions were found:

- Posture 3 (arranging merchandise – glasses – on the top shelf) with a final score of 7, level 4 (considered the most critical level of the method). As a recommendation, immediate changes to the task performed are required. The most alarming aspects are the arm angle (which is above

the shoulder and is maintained for more than a minute), the raised arms, the wrist position (extreme pronation), and the neck angle (extension).

- Posture 4 (dropping a box to count inventory – sportswear) with a final score of 7, level 4, recommending immediate changes to the task. In this posture, the most alarming aspects were found to be the arm angle (above the shoulder), forearm angle (no flexion), wrist angle (extreme supination), and neck angle (extension).
- Posture 5 (sports clothing count – inventory), with a score of 7, level 4, with the recommendation to make immediate changes to the task performed. The most critical aspects considered were the angle of the arms (fully extended), the angle of the forearm (completely straight), and the angle of the torso (which, combined with the leg posture, does not allow for symmetrical weight distribution).

4.2 Owas method

Positions 1 (packing sold merchandise), 2 (arranging merchandise – glasses), and 3 (arranging merchandise – glasses – on the top shelf) are classified as risk category 1, as they involve a straight back, arms in a safe position, straight legs, and handling less than 10 kg. These postures are normal, do not represent a significant risk, and do not require corrective action. Posture 4 (leaving a box for inventory counting – sportswear) is in risk category 3, with a bent back, both arms raised, standing or squatting with both legs bent and the weight balanced between them, and with a load of less than 10 kg. The load caused by this posture has extremely harmful effects on the musculoskeletal system; corrective action is required as soon as possible. Posture 5 is in risk category 2, with a bent back, both arms lowered, kneeling, and with a load of less than 10 kg. This posture has the potential to cause damage to the musculoskeletal system, and corrective actions are required in the near future. Based on the frequency of each body part (arms, legs, and back), it was found that the positions of forward bending or flexing the back (40%), raised arms (40%), and knees bent (20%) fall into risk category 2, with the potential to cause damage to the musculoskeletal system, and corrective actions are required in the near future.

5. CONCLUSIONS

Based on the results obtained using the RULA and OWAS posture assessment methods, it is concluded that postures 3 (arranging merchandise – glasses – on the top shelf), 4 (dropping a box to count inventory – sportswear), and 5 (counting sportswear – inventory) can cause musculoskeletal damage due to the angles of the neck, arms, forearms, torso, leg position, and wrist angle and position. Postures 1 (packing sold merchandise) and 2 (arranging merchandise – glasses) are less critical, falling within an acceptable range or posing minimal risk. The duration of the task and whether it is performed more than four times per minute are taken into account.

The recommendations are to conduct a more in-depth analysis of each posture, seeking solutions or improvements to minimize the risk of musculoskeletal damage. Designating specific areas to perform tasks such as counting sportswear (inventory), placing shelves within easy reach of the employee, and providing a two-step folding ladder (so that it doesn't take up much space and isn't too risky to use, but still allows the employee to maintain a better posture to reduce strain on their neck, arms, forearms, and wrists) are some of the solutions that were provided.

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INTRODUCTORY ANALYSIS OF MENTAL WORKLOAD USING GALVANIC SKIN RESPONSE

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Resumen: Este trabajo analiza la carga mental de trabajo en entornos digitalizados mediante la integración del método subjetivo NASA-TLX y la medición fisiológica de la Respuesta Galvánica de la Piel (GSR), evaluando a 11 jóvenes adultos mexicanos que realizaron una tarea aritmética diseñada para inducir alta demanda cognitiva; los resultados mostraron un incremento significativo en la actividad electrodermal durante la tarea, así como elevadas percepciones de demanda mental, esfuerzo, presión temporal y frustración, evidenciando una relación positiva entre los indicadores fisiológicos y las evaluaciones subjetivas, lo que confirma la utilidad del GSR como herramienta complementaria para medir objetivamente la carga mental y contribuir al diseño ergonómico de entornos laborales más seguros y eficientes.

Palabras clave: carga mental de trabajo, NASA-TLX, Respuesta Galvánica de la piel

Relevancia para la ergonomía: Este estudio contribuye al campo de la ergonomía al avanzar en el uso de técnicas fisiológicas, específicamente la Respuesta Galvánica de la Piel (GSR), para evaluar la carga mental mediante indicadores objetivos que no dependen de los juicios subjetivos de los participantes, los cuales suelen estar influenciados por sesgos cognitivos, estados emocionales o condicionamientos culturales.

Abstract: This work analyzes mental workload in digitalized environments by integrating the subjective NASA-TLX method with physiological measurements of Galvanic Skin Response (GSR), evaluating 11 young Mexican adults who performed an arithmetic task designed to induce high cognitive demand; results showed a significant increase in electrodermal activity during the task, along with high perceptions of mental demand, effort, time pressure, and frustration, revealing a positive relationship between physiological indicators and subjective assessments,

thus confirming the usefulness of GSR as a complementary tool for objectively measuring mental workload and contributing to the ergonomic design of safer and more efficient work environments.

Keywords. Mental workload, NASA-TLX, Galvanic skin response.

Relevance to Ergonomics: This study contributes to the field of ergonomics by advancing the use of physiological techniques, specifically Galvanic Skin Response (GSR), to evaluate mental workload through objective indicators that do not depend on participants' subjective judgments, which are often influenced by cognitive biases, emotional states, or cultural conditioning.

1. INTRODUCTION

The growing cognitive complexity in highly digitalized work environments has been identified as a factor that overloads workers' attentional resources, causing mental fatigue and a reduction in operational efficiency (Arana-De las Casas et al., 2021). This phenomenon, known as mental workload, refers to the amount of cognitive processing required to perform a task within a given time interval. Its assessment has become a priority for the prevention of mental disorders and the promotion of occupational health (Barajas-Bustillos et al., 2023; Rubio, et al., 2001; Rusnock & Borghetti, 2018). Recent studies have expanded this perspective by demonstrating that mental workload not only affects individual performance but also negatively influences sleep quality and overall well-being, as documented in medical and psychiatric personnel (Fan et al., 2021). In this context, mental workload can be conceptualized as the demand for cognitive resources involved in carrying out a task, generating a direct impact on human performance and levels of work-related stress. Currently, measuring this variable represents a central focus in ergonomic research aimed at optimizing comfort, satisfaction, efficiency, and safety in the workplace.

The evaluation of mental workload can be approached through subjective or physiological methods. Among the former, the NASA-TLX (Task Load Index) has become the benchmark subjective method, assessing six dimensions: mental demand, physical demand, temporal demand, effort, performance, and frustration (Arquer & Nogareda, 2001). In the case of physiological methods, notable techniques include those obtained through electroencephalography (EEG), electrocardiography (ECG), and those that make use of Galvanic Skin Response.

Galvanic Skin Response (GSR), also known as Electrodermal Activity (EDA), is a physiological signal that measures variations in the skin's electrical conductance, primarily due to the activity of eccrine sweat glands. This activity is controlled by the sympathetic nervous system, which makes GSR a sensitive indicator of autonomic activation associated with states of arousal, stress, and cognitive load (Widyanti et al., 2017).

Electrodermal activity (EDA) presents (at least) two analytically distinguishable components:

1. The tonic component, or Skin Conductance Level (SCL), a slow-varying measure that reflects autonomic tone or the basal level of sustained activation throughout a condition (e.g., rest vs. task).
2. The phasic component, or Skin Conductance Responses (SCR), a fast-varying measure that is typically event-dependent and sensitive to novel or emotionally significant stimuli, attentional load, and cognitive demand.

The explicit separation of both components enhances interpretative validity by allowing SCL to capture state, sustained arousal, while SCR characterize reactivity, transient event-related fluctuations.

The mean SCL summarizes the degree of sustained sympathetic activation within a time window (or experimental phase), making it suitable for contrasting conditions (e.g., baseline vs. task) and describing stable inter-individual differences in arousal. Theoretically, an increase in SCL suggests greater “physiological preparedness” (e.g., fight-or-flight) and heightened alertness; empirically, it has been extensively used to characterize the impact of stress, pain, emotion, and cognitive load on autonomic tone. As a basal indicator, SCL is less sensitive to the exact timing of discrete stimuli and therefore complements faster reaction-based metrics. (Braithwaite et al., 2013; Tsirmpas et al., 2025)

1.2 Objective

The objective of this article is to analyze and evaluate mental workload in digitalized work environments through the integration of subjective and physiological methods, particularly the NASA-TLX and Galvanic Skin Response (GSR), to determine its impact on performance, well-being, and stress levels in a Mexican population.

1.3 Scope and Delimitation

This study focuses on the assessment of mental workload in a sample of young Mexican adults aged 20 to 25 years who reported being in good health. The research is limited to the analysis of subjective and physiological indicators of cognitive load within this specific demographic group, using the NASA-TLX questionnaire and Galvanic Skin Response (GSR) measurements as primary evaluation tools. Consequently, the findings are bounded by the characteristics of this population and may not be generalizable to individuals of different age ranges, health conditions, cultural backgrounds, or occupational contexts. The scope of the study is restricted to controlled experimental conditions designed to examine cognitive demands, excluding broader organizational or environmental factors that may influence mental workload.

2. METHODOLOGY

For this work, the methodology was divided in four sections and are shown in Figure 1.

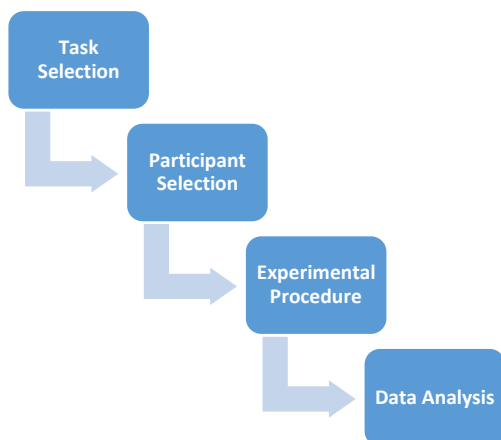


Figure 1. Methodology

2.1 Task Selection

To induce an appropriate level of cognitive demand, a task with predominantly cognitive rather than physical requirements was selected. Participants completed a series of arithmetic operations delivered through a computer program. The task consisted of performing continuous subtraction from a randomly generated number. Each operation had to be solved within 30 seconds. Correct responses were displayed in green, while incorrect or unanswered items were marked as errors. This type of task is widely used to elicit cognitive load and activate physiological stress responses, making it suitable for analyzing mental workload through both subjective and physiological indicators. Figure 2 shows a screenshot of the software that implement the task.

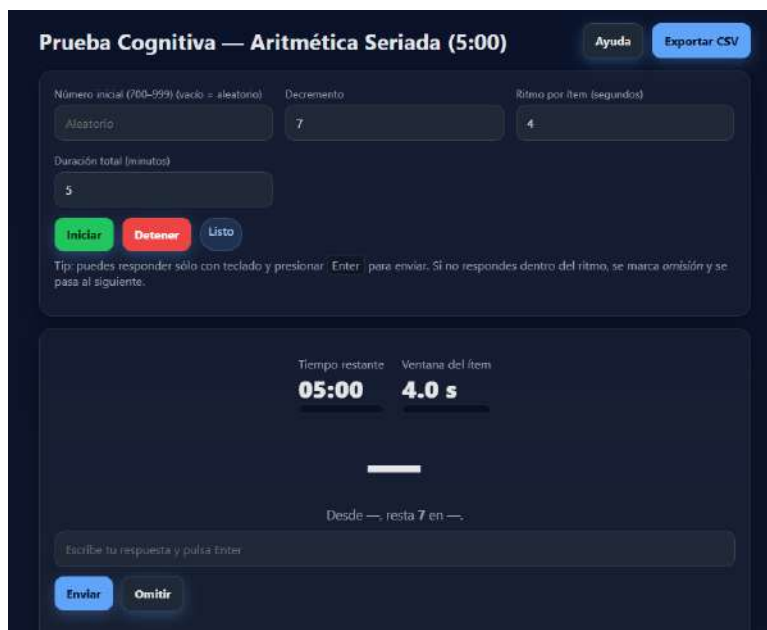


Figure 2. Screenshot of the software implementation.

2.2 Participant Selection

Participants were recruited through convenience sampling. The study focused specifically on Mexican young adults aged 20 to 25 years who self-reported being in good health, in alignment with the scope of the research. To control for confounding physiological factors, individuals with known dermatological conditions, neurological disorders, or any condition affecting autonomic responses were excluded. Additionally, participants were instructed to abstain from consuming alcohol or psychoactive substances for at least 48 hours prior to data collection due to their documented impact on physiological arousal.

A total of 11 university students participated in the study. All were within the predefined age range and reported no medical conditions that could influence GSR measurements.

2.3 Experimental Procedure

1. Each participant completed the following steps during a single experimental session:
2. Informed Consent. Participants were briefed on the purpose and procedures of the study and provided written informed consent.
3. Sensor Placement and Instructions. Participants were equipped with a GSR sensor device placed on their fingers following standard electrodermal activity measurement guidelines. The GSR sensor was the Seed Studio© Grove GSR (*Grove - GSR Sensor | Seeed Studio Wiki, 2023*). They were also instructed on how to complete the NASA TLX questionnaire using a digital form. The version used assessed the six NASA TLX dimensions without pairwise weighting.

4. Baseline Measurement. A baseline GSR recording was obtained while the participant remained seated and relaxed for a short period. This served as a reference for later comparisons.
5. Task Execution. Participants performed the cognitive arithmetic task continuously for 15 minutes. GSR data were recorded throughout the task to capture physiological correlations of cognitive load. Figure 3 shows a participant performing the task.
6. Immediately after completing the task, participants filled out the NASA TLX questionnaire to provide subjective evaluations of mental workload.



Figure 3. Participant performing the task

2.4 Data Analysis

Physiological data were processed using Python package Neutokit2 to extract relevant electrodermal activity indicators (Makowski et al., 2021). These indicators, Skin Conductance Level (SCL) and Skin Conductance Response (SCR), were used to compare baseline and task periods, enabling the identification of increases in autonomic activation associated with cognitive load.

Subjective workload scores obtained through NASA-TLX were analyzed to determine perceived mental, physical, and temporal demand, effort, performance, and frustration levels.

Statistical analyses were performed using JASP® with a significance level of $\alpha = 0.05$. Comparisons were conducted to examine whether increases in GSR

indicators corresponded with higher mental workload ratings reported in the NASA-TLX, thus integrating physiological and subjective measurements to fulfill the research objective.

3. RESULTS

Table 1 shows the values obtained for the mean SCL and SCR that were observed both at the baseline level and during task performance. The results show a consistent increase in electrodermal activity during the task phase compared to the baseline phase. In terms of the tonic component, the mean SCL level increased from 4.09 μ S at baseline to 6.58 μ S during task performance, indicating greater sustained activation of the sympathetic nervous system. In parallel, the frequency of phasic responses (SCR) also rose significantly, increasing from 3.14 to 6.72 peaks/min, reflecting heightened reactivity to task demands. Although the magnitude of the change varied across participants, the overall pattern demonstrates a robust increase in both tonic and phasic activity, suggesting that the task elicited a clear rise in physiological activation associated with arousal and the processing of relevant stimuli.

Table 1. Results obtained for mean SCL level and SCR frequency.

Participant	Mean SCL (μ S) BASAL	Mean SCL (μ S) TASK	SCR Frequency (p/m) BASAL	SCR Frequency (p/m) TASK
1	2.1	9.4	2.1	8.3
2	3.1	8.2	1.9	6.4
3	2.8	6.1	5.8	9.2
4	4.3	5.8	3.2	11.5
5	3.8	6.9	2.8	6.2
6	6.4	6.8	3.6	4.8
7	3.2	4.6	2.4	2.8
8	5.2	5.4	3.4	8.3
9	5.5	4.5	3.6	2.3
10	5.3	5.7	3.1	7.3
11	3.3	9	2.7	6.9
Average	4.09	6.58	3.14	6.72

Table 2 presents the results obtained using the NASA-TLX, divided into the scores for each of the five dimensions it assesses, confirming that the selected task has a high cognitive component.

Table 2. NASA-TLX results.

Participant	Mental Demand	Physical Demand	Temporal Demand	Effort	Performance	Frustration	Total
1	90	20	40	60	80	60	350
2	80	10	80	70	80	50	370
3	40	10	50	40	20	40	200
4	80	20	60	70	50	70	350
5	50	10	40	20	40	30	190
6	80	20	80	30	50	40	300
7	80	20	30	30	30	30	220
8	40	10	60	40	30	60	240
9	60	10	60	50	60	60	300
10	40	10	30	40	100	10	230
11	70	10	20	30	60	10	200
Mean	64.55	13.64	50	43.64	54.55	41.82	268.18
Standard Deviation	19.16	5.05	20	16.9	24.64	20.4	67.65

Due to the sample size, the comparison between the results was conducted under the assumption of non-normality. To determine whether there was a difference between the baseline state and the task-execution state in the mean SCL level, the nonparametric Wilcoxon test was used, with the results shown in Table 3. A p-value of 0.003 was obtained, providing evidence of an increase in mean SCL due to task performance. In the case of SCR frequency, a p-value of 0.002 was obtained, indicating a significant increase in SCR frequency.

Once the results from both methods were obtained, Spearman's correlation test was applied. The analysis between mean SCL and NASA-TLX scores yielded a p-value of 0.027 and a rho value of 0.659, as shown in Table 3. This indicates a statistically significant positive correlation, suggesting that higher mean SCL levels are associated with higher perceived workload according to the NASA-TLX. Additionally, a Spearman correlation analysis was conducted between SCR frequency and NASA-TLX scores. This analysis resulted in a p-value of 0.019 and a rho value of 0.658, indicating a statistically significant positive correlation between SCR frequency and perceived workload.

Table 3. JASP results of Wilcoxon test.

Wilcoxon signed-rank test.

Measure 1			Measure 2		W	z	df	p
Average SCL (ms) BASAL	-		Average SCL (ms) TASK		4.000	-2.578		0.003
SCR Frequency (p/m) BASAL	-		SCR Frequency (p/m) TASK		3.000	-2.667		0.002

Note. For all tests, the alternative hypothesis specifies that Measure 1 is less than Measure 2. For example, Average SCL (ms) BASAL is less than Average SCL (ms) TASK.

Note. Wilcoxon signed-rank test.

4. CONCLUSIONS

NASA-TLX scores revealed that participants perceived the arithmetic task as moderately to highly mentally demanding, with particularly elevated scores in the dimensions of mental demand, effort, temporal demand, and frustration. Performance scores showed variability depending on individual numerical reasoning abilities, but overall, a moderate level of perceived challenge was confirmed.

One of the central findings was the positive association between GSR indicators and subjective workload. Participants who exhibited greater increases in GSR during the task reported higher mental workload scores on the NASA-TLX. This relationship supported the use of GSR as a complementary tool to subjective assessment methods.

Given that the sample consisted of healthy Mexican young adults aged 20 to 25, the data showed relatively low physiological variability among participants. This controlled demographic facilitated a clearer identification of workload-related trends, free from confounding effects related to age, chronic illness, or substance use. Finally, the continuous subtraction task was confirmed to be effective in inducing sustained cognitive load over the 15-minute period, as evidenced by the increase in GSR activity and the elevated mental demand scores in the NASA-TLX.

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STRESS MANAGEMENT, COGNITIVE FUNCTIONS, AND OCCUPATIONAL WELL-BEING IN INDUSTRIAL WORKERS: A CORRELATIONAL STUDY

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Resumen: Las crecientes demandas cognitivas de los entornos industriales digitalizados han intensificado la necesidad de comprender cómo el estrés ocupacional y los recursos psicológicos se relacionan con el funcionamiento cognitivo. El presente estudio examinó las relaciones asociativas y multivariadas entre el estrés percibido, el burnout, el sentido de coherencia, la capacidad de trabajo, las fallas cognitivas subjetivas y el desempeño cognitivo objetivo en una muestra de 200 trabajadores industriales (media de edad = 38.6 años, DE = 8.9; 42% mujeres). Se empleó un diseño correlacional con instrumentos neuropsicológicos y psicosociales estandarizados. Los análisis descriptivos indicaron niveles moderados de estrés percibido (Media = 0.46, DE = 0.15) y agotamiento emocional (Media = 2.9, DE = 1.1), junto con una variabilidad interindividual sustancial en el desempeño atencional y ejecutivo. Las correlaciones bivariadas revelaron asociaciones negativas significativas entre el estrés percibido y la atención ($r = -0.41$, $p < 0.001$), la memoria de trabajo ($r = -0.36$, $p < 0.001$) y las funciones ejecutivas ($r = -0.39$, $p < 0.001$). El agotamiento emocional mostró asociaciones negativas similares con el desempeño ejecutivo ($r = -0.34$, $p < 0.001$) y fuertes correlaciones positivas con las fallas cognitivas ($r = .58$, $p < .001$). El estrés percibido se asoció fuertemente con las fallas cognitivas ($r = 0.62$, $p < 0.001$) y de manera inversa con la capacidad de trabajo ($r = -0.45$, $p < 0.001$). En contraste, el sentido de coherencia presentó correlaciones positivas con la atención ($r = 0.37$, $p < 0.001$) y las funciones ejecutivas ($r = 0.35$, $p < 0.001$), así como correlaciones negativas con el burnout ($r = -0.49$, $p < 0.001$) y las fallas cognitivas ($r = -0.44$, $p < 0.001$). Los análisis de regresión múltiple confirmaron que el estrés percibido ($\beta = -0.29$, $p < 0.001$) y el agotamiento emocional ($\beta = -0.21$, $p = 0.004$) fueron predictores negativos significativos del funcionamiento ejecutivo, mientras que el

sentido de coherencia emergió como predictor positivo ($\beta = 0.24$, $p = 0.002$). El modelo global explicó el 32% de la varianza en el desempeño ejecutivo ($R^2 = 0.32$, $F(4,195) = 22.94$, $p < 0.001$). Se observaron patrones similares para los resultados atencionales ($R^2 = 0.29$). La integración de medidas subjetivas y objetivas reveló una convergencia moderada a fuerte entre las fallas cognitivas y las medidas atencionales y ejecutivas de laboratorio (r absoluto entre 0.33 y 0.47), lo que respalda enfoques de evaluación multidimensional. En conjunto, los hallazgos demuestran una interacción sólida y estadísticamente significativa entre el estrés ocupacional, los recursos psicológicos y el funcionamiento cognitivo. Los resultados subrayan el papel protector del sentido de coherencia y destacan la relevancia de los marcos cognitivo-conductuales y salutogénicos para promover la sostenibilidad cognitiva y la resiliencia en contextos industriales de alta demanda.

Palabras clave: Estrés percibido; fallas cognitivas; funciones ejecutivas; recursos psicológicos; ergonomía cognitiva.

Relevancia para la ergonomía: Los hallazgos del presente estudio son altamente relevantes para la ergonomía, particularmente en los ámbitos de la ergonomía cognitiva y la ergonomía de la salud ocupacional. Los sistemas industriales contemporáneos dependen cada vez más de la atención sostenida, el control ejecutivo, el procesamiento rápido de la información y la toma de decisiones adaptativa. Las asociaciones negativas observadas entre el estrés percibido, el agotamiento emocional y el desempeño cognitivo objetivo indican que la carga psicosocial constituye un factor de riesgo ergonómico significativo que afecta la interacción humano-sistema. Desde la perspectiva de la ergonomía cognitiva, los decrementos atencionales y ejecutivos relacionados con el estrés pueden comprometer la conciencia situacional, la detección de errores, la inhibición de respuestas y la eficiencia en el cambio de tareas, capacidades fundamentales en entornos industriales automatizados y de alta confiabilidad. La fuerte convergencia entre las fallas cognitivas subjetivas y las medidas atencionales y ejecutivas obtenidas en laboratorio refuerza la importancia ergonómica de integrar indicadores de autoinforme en los protocolos de evaluación de riesgos. Los modelos ergonómicos tradicionales han enfatizado principalmente la carga biomecánica y el esfuerzo físico; sin embargo, los resultados destacan que la carga cognitiva y el estrés psicosocial son determinantes igualmente críticos para la sostenibilidad del desempeño y la seguridad operativa. Los trabajadores con niveles elevados de estrés y burnout pueden presentar mayor susceptibilidad a lapsos atencionales, tiempos de reacción más lentos y disminución de la memoria de trabajo, aumentando así la probabilidad de error humano, incidentes potenciales y pérdidas de productividad. De manera importante, el papel protector del sentido de coherencia subraya el valor de los enfoques salutogénicos dentro de las intervenciones ergonómicas. Fortalecer la comprensibilidad, la manejabilidad y la significatividad en el diseño del trabajo se alinea directamente con los principios ergonómicos de claridad de tareas, suficiencia de recursos y compromiso motivacional. Estos hallazgos respaldan la integración de estrategias orientadas al fortalecimiento de recursos psicosociales en los programas ergonómicos,

complementando los esfuerzos tradicionales de rediseño físico. En conjunto, el estudio amplía la teoría ergonómica al vincular empíricamente la carga psicosocial, el funcionamiento cognitivo y la capacidad de trabajo percibida en contextos industriales. Asimismo, respalda un marco ergonómico multidimensional en el que la sostenibilidad cognitiva, la regulación del estrés y la resiliencia psicológica se consideran componentes centrales del diseño de sistemas seguros, eficientes y centrados en el ser humano.

Abstract: The increasing cognitive demands of digitally mediated industrial environments have intensified the need to understand how occupational stress and psychological resources relate to cognitive functioning. This study examined associative and multivariate relationships among perceived stress, burnout, sense of coherence, work ability, subjective cognitive failures, and objective cognitive performance in a sample of 200 industrial workers (Mean age = 38.6 years, SD = 8.9; 42% female). A correlational design with standardized neuropsychological and psychosocial measures was implemented. Descriptive analyses indicated moderate levels of perceived stress ($M = 0.46$, $SD = 0.15$) and emotional exhaustion ($M = 2.9$, $SD = 1.1$), alongside substantial interindividual variability in attentional and executive performance. Bivariate correlations revealed significant negative associations between perceived stress and attention ($r = -0.41$, $p < 0.001$), working memory ($r = -0.36$, $p < 0.001$), and executive functioning ($r = -0.39$, $p < 0.001$). Emotional exhaustion demonstrated similar negative associations with executive performance ($r = -0.34$, $p < 0.001$) and strong positive correlations with cognitive failures ($r = 0.58$, $p < 0.001$). Perceived stress was strongly associated with cognitive failures ($r = 0.62$, $p < 0.001$) and inversely associated with work ability ($r = -0.45$, $p < 0.001$). In contrast, sense of coherence showed positive correlations with attention ($r = 0.37$, $p < 0.001$) and executive functioning ($r = 0.35$, $p < 0.001$), and negative correlations with burnout ($r = -0.49$, $p < 0.001$) and cognitive failures ($r = -0.44$, $p < 0.001$). Multiple regression analyses confirmed that perceived stress ($\beta = -0.29$, $p < 0.001$) and emotional exhaustion ($\beta = -0.21$, $p = 0.004$) were significant negative predictors of executive function, while sense of coherence emerged as a positive predictor ($\beta = 0.24$, $p = 0.002$). The overall model explained 32% of the variance in executive performance ($R^2 = 0.32$, $F(4,195) = 22.94$, $p < 0.001$). Similar patterns were observed for attentional outcomes ($R^2 = 0.29$). Integration of subjective and objective measures revealed moderate-to-strong convergence between cognitive failures and laboratory-based attentional and executive measures ($|r|$ range = 0.33-0.47), supporting multidimensional assessment approaches. Overall, the findings demonstrate a robust and statistically meaningful interplay between occupational stress, psychological resources, and cognitive functioning. The results underscore the protective role of sense of coherence and highlight the relevance of cognitive-behavioral and salutogenic frameworks for promoting cognitive sustainability and resilience in high-demand industrial contexts.

Keywords: Perceived stress; cognitive failures; executive functions; psychological resources; cognitive ergonomics.

Relevance to Ergonomics: The present findings are highly relevant to ergonomics, particularly within the domains of cognitive ergonomics and occupational health ergonomics. Contemporary industrial systems increasingly rely on sustained attention, executive control, rapid information processing, and adaptive decision-making. The demonstrated negative associations between perceived stress, emotional exhaustion, and objective cognitive performance suggest that psychosocial strain constitutes a significant ergonomic risk factor affecting human-system interaction. From a cognitive ergonomics perspective, stress-related decrements in attention and executive functioning may compromise situational awareness, error detection, response inhibition, and task-switching efficiency-core capacities required in automated and high-reliability industrial environments. The strong convergence between subjective cognitive failures and laboratory-based attentional and executive measures further reinforces the ergonomic importance of integrating self-report indicators into risk assessment protocols. Traditional ergonomic models often emphasize biomechanical load and physical strain; however, the present results highlight that cognitive load and psychosocial stress are equally critical determinants of performance sustainability and operational safety. Workers experiencing elevated stress and burnout may be more susceptible to attentional lapses, delayed reactions, and reduced working memory capacity, thereby increasing the probability of human error, near misses, and productivity losses. Importantly, the protective role of sense of coherence underscores the value of salutogenic approaches within ergonomic interventions. Strengthening comprehensibility, manageability, and meaningfulness in work design aligns directly with ergonomic principles of task clarity, resource adequacy, and motivational engagement. These findings support the integration of psychosocial resource enhancement strategies into ergonomic programs, complementing traditional physical redesign efforts. Overall, the study advances ergonomic theory by empirically linking psychosocial strain, cognitive functioning, and perceived work ability within industrial contexts. It supports a multidimensional ergonomic framework in which cognitive sustainability, stress regulation, and psychological resilience are considered central components of safe, efficient, and human-centered system design.

1. INTRODUCTION

The rapid transformation of industrial environments driven by automation, digitalization, and advanced human-machine systems has significantly increased cognitive demands on workers. In contemporary production systems aligned with Industry 4.0 and emerging Industry 5.0 paradigms, industrial employees are required to sustain attention, monitor complex interfaces, process information rapidly, and make adaptive decisions under time pressure and uncertainty. These evolving demands have shifted industrial work from predominantly physical execution to cognitively intensive performance, where mental efficiency and resilience are critical determinants of safety and productivity (Antonaci et al., 2024).

Occupational stress has emerged as a central factor influencing cognitive functioning in high-demand work settings. According to contemporary neurocognitive research, prolonged exposure to psychosocial stressors—such as high workload, shift schedules, role ambiguity, and limited decision latitude—can impair executive control, attention regulation, working memory, and processing speed (Shields et al., 2020; Starcke & Brand, 2022). Stress-related activation of the hypothalamic–pituitary–adrenal (HPA) axis and sustained cortisol release may compromise prefrontal cortical functioning, thereby affecting higher-order cognitive processes essential for safe and efficient industrial performance. These impairments increase vulnerability to cognitive failures, operational errors, and reduced productivity.

Recent empirical studies in occupational populations confirm these associations. A systematic review examining work-related determinants of cognitive functioning reported that high occupational stress, extended working hours, and shift work are consistently associated with diminished cognitive performance across attention and executive domains (Bufano et al., 2024). Similarly, research conducted in high-risk industrial contexts demonstrated that workers exposed to chronic occupational stress exhibited measurable reductions in executive flexibility, planning capacity, and working memory performance (Çelik, 2025). Such findings underscore the importance of examining cognitive functioning as both an outcome and mediator of occupational stress.

Beyond its cognitive consequences, occupational stress is closely linked to work-related well-being. Occupational well-being encompasses emotional balance, job satisfaction, engagement, work ability, and the absence of burnout symptoms. Burnout, characterized by emotional exhaustion, depersonalization, and reduced professional efficacy, has been identified as a critical outcome of chronic job stress (Maslach and Leiter, 2021). Emotional exhaustion has been associated with reduced attentional resources and impaired executive functioning, suggesting reciprocal relationships between psychological strain and cognitive efficiency.

However, stress effects are not uniform across individuals. Psychological resources may buffer the impact of stress on both cognitive performance and well-being. Within the salutogenetic framework, sense of coherence (SOC) represents a global orientation characterized by comprehensibility, manageability, and meaningfulness. Individuals with higher SOC are more likely to perceive occupational demands as structured and manageable, mobilize adaptive coping strategies, and maintain psychological stability under strain (Mittelmark et al., 2022). Recent occupational research suggests that stronger SOC is associated with lower perceived stress, reduced burnout, and better self-reported cognitive functioning (Super et al., 2021).

Cognitive-behavioral models further emphasize the role of appraisal and cognitive restructuring in stress management. According to transactional stress theory, stress responses depend on subjective evaluations of environmental demands and coping resources. Maladaptive appraisals and dysfunctional beliefs may amplify perceived threat and cognitive load, whereas cognitive restructuring and coping skill training can reduce psychological strain and preserve executive functioning (Lazarus and Folkman, 1984; updated applications discussed in Zhang

et al., 2023). Contemporary workplace interventions increasingly incorporate cognitive-behavioral stress management techniques to enhance resilience and improve occupational well-being.

From a cognitive ergonomics perspective, sustainable industrial performance depends on aligning task demands with human cognitive capacities. Excessive cognitive workload can overload attentional systems and reduce decision accuracy, whereas optimized work design, clear interface structures, and adequate recovery opportunities can mitigate stress-related decrements in performance (Antonaci et al., 2024). Investigating the interrelationships among cognitive workload, executive function, stress perception, and well-being is therefore central to promoting human-centered industrial systems.

Despite growing recognition of these connections, there remains a need for integrative research combining objective cognitive assessments with validated psychosocial measures in industrial populations. Many occupational studies rely primarily on self-report instruments, potentially overlooking measurable cognitive variations. Conversely, laboratory-based cognitive research often neglects contextual occupational variables. A relational, multivariate approach that integrates standardized cognitive testing with measures of perceived stress, sense of coherence, burnout, cognitive failures, and work ability can provide a more comprehensive understanding of associative patterns within real-world industrial settings.

Accordingly, this chapter adopts a correlational framework to examine relationships between occupational stress, cognitive functions, and work-related well-being in industrial workers. By analyzing associations among perceived stress, objective cognitive performance, psychological resources, burnout dimensions, cognitive workload, and work ability, the study aims to identify relational patterns that inform evidence-based strategies for enhancing resilience, sustaining executive performance, and promoting occupational well-being in technologically evolving industrial environments.

2. OBJECTIVES

To examine relationships between occupational stress, cognitive functions, and work-related well-being in industrial workers. The chapter analyzes links between perceived stress and cognitive performance, psychological resources (sense of coherence) and objective cognitive measures, subjective cognitive failures and standardized test outcomes, burnout dimensions, relational patterns across cognitive-behavioral and salutogenetic training contexts, and interrelationships among cognitive workload, executive function, and occupational well-being.

3. METHODOLOGY

3.1 Research design

It was employed a controlled correlational design with pre- and post-assessments to examine relationships among occupational stress, cognitive functions, and work-related well-being in industrial workers. The design was explicitly non-experimental, as the primary objective was to analyze associative and multivariate patterns rather than to establish direct causal effects. In occupational health research conducted in real-world industrial environments, experimental manipulation of stress exposure is often ethically inappropriate and practically unfeasible. Consequently, correlational approaches represent a methodologically sound strategy for investigating naturally occurring variations in perceived stress, psychological resources, burnout symptoms, and objective cognitive performance. As emphasized by Spector (2022) in contemporary methodological guidance for industrial-organizational research, non-experimental designs are appropriate when the aim is to understand predictive and relational patterns among continuous organizational variables without artificially manipulating core constructs.

Correlational multivariate designs are particularly well suited to the investigation of complex psychosocial systems characterized by reciprocal and overlapping influences. Occupational stress, executive functioning, emotional exhaustion, cognitive failures, and work ability are not isolated phenomena but rather interdependent components of a dynamic cognitive-affective network. Multivariate statistical modeling allows simultaneous examination of these relationships while controlling for shared variance among predictors, thereby providing a more precise understanding of relative contributions across domains. This approach aligns with contemporary occupational cognitive research, including the systematic review conducted by Paolo Bufano et al. (2024), which highlights the multifactorial determinants of work-related cognitive functioning and recommends integrative analytic strategies capable of disentangling overlapping psychosocial and cognitive effects.

Although non-experimental in nature, the study incorporated a controlled structural component through the inclusion of three parallel conditions: a cognitive-behavioral stress management program, a salutogenetic health promotion program, and a wait-list control group. This structure permitted examination of relational patterns across theoretically distinct training contexts while maintaining the correlational focus of the analyses. The intent was not to evaluate intervention efficacy in a causal framework, but rather to explore how variables co-varied within and across these contexts. Such an approach reflects contemporary recommendations in occupational intervention research, which advocate for the examination of dynamic relational processes even when causal inference is not the primary objective.

The inclusion of pre- and post-assessments further strengthened the design by allowing observation of temporal relational patterns across measurement points. Repeated assessment provides insight into whether associations among stress perception, sense of coherence, burnout dimensions, executive functioning,

cognitive workload, and work ability remain stable or shift over time. Importantly, these repeated measures were employed to deepen relational analysis rather than to imply treatment causality. Longitudinal and repeated-measure approaches are increasingly encouraged in occupational stress research to capture the evolving interplay between cognitive and psychosocial variables. As discussed in meta-analytic evaluations of workplace stress management interventions by Yuan Zhang et al. (2023), integrating objective cognitive indicators with psychosocial assessments across time enhances understanding of resilience processes and adaptive functioning in occupational settings.

The selected design is also theoretically aligned with multidimensional occupational health models, particularly the Job Demands-Resources framework developed by Bakker and Demerouti (2023). This model conceptualizes stress and well-being as outcomes of interactions between job demands and personal resources, requiring analytic strategies capable of examining simultaneous predictors and outcomes in naturalistic environments. Additionally, both cognitive-behavioral and salutogenetic perspectives conceptualize stress processes as relational and systemic rather than strictly linear, further supporting the appropriateness of multivariate correlational modeling.

The controlled correlational design with pre- and post-assessments was selected because it respects ethical constraints inherent in occupational stress research, captures naturally occurring variability in psychosocial and cognitive constructs, permits simultaneous examination of multiple interrelated variables, integrates objective neuropsychological testing with validated self-report measures, and allows temporal observation of relational patterns without exceeding the inferential boundaries of non-experimental research. This methodological framework provides a robust and theoretically coherent basis for examining the complex interrelationships among occupational stress, cognitive functioning, psychological resources, burnout, cognitive workload, and occupational well-being in contemporary industrial contexts.

3.2 Participants

The study sample consisted of 200 adult industrial workers who were voluntarily recruited from active industrial employment sectors, including manufacturing, production, and technical operations. Recruitment was conducted through organizational announcements, informational meetings, and internal communication channels within participating companies. Workers were informed about the study's objectives, procedures, time commitments, and assessment components prior to enrollment. Participation was entirely voluntary, and no coercive incentives were used. This recruitment strategy was intended to ensure ecological validity by sampling individuals actively engaged in real-world industrial environments characterized by cognitive workload, operational demands, and psychosocial stress exposure.

To ensure methodological rigor and protect the validity of neuropsychological findings, clearly defined inclusion and exclusion criteria were applied. Inclusion criteria required that participants (a) be actively employed in an industrial setting at

the time of data collection, (b) be at least 18 years of age, and (c) possess sufficient literacy and cognitive capacity to understand instructions and complete standardized psychological and neurocognitive assessments. The age criterion ensured that all participants met legal standards for adult informed consent and reduced developmental variability associated with adolescent cognitive maturation. The requirement of active employment ensured that stress and workload measures reflected current occupational exposure rather than retrospective or hypothetical conditions.

Exclusion criteria were implemented to minimize potential confounding variables that could distort interpretation of objective cognitive performance. Participants were excluded if they reported (a) diagnosed neurological disorders (e.g., epilepsy, traumatic brain injury with persistent cognitive sequelae, neurodegenerative conditions), (b) severe psychiatric disorders that could substantially impair cognitive functioning (e.g., psychotic disorders, severe major depressive episodes with cognitive impairment), or (c) use of medication known to significantly affect cognitive processes, such as strong sedatives, antipsychotics, or medications with pronounced central nervous system effects. These criteria were consistent with methodological standards in occupational neuropsychological research, which emphasize the importance of controlling for medical and pharmacological influences when assessing executive functioning, attention, and memory performance in working populations (Çelik, 2025). By applying these exclusion parameters, the study sought to ensure that observed variability in cognitive test outcomes more accurately reflected psychosocial and occupational factors rather than underlying clinical conditions.

Demographically, the sample represented a working adult population of industrial sectors, encompassing a range of ages, job roles, and levels of technical responsibility. Although the primary analytical focus of this chapter is relational rather than demographic, capturing variability in occupational roles enhanced the generalizability of findings within industrial contexts. Participants included machine operators, technical staff, supervisors, and maintenance personnel, reflecting diverse cognitive demands and exposure levels within industrial systems.

Ethical safeguards were implemented throughout the research process. All participants provided written informed consent after receiving detailed information about study procedures, potential risks, benefits, and data protection measures. They were informed of their right to decline participation or withdraw from the study at any time without penalty or adverse employment consequences. Confidentiality was strictly maintained through anonymized coding of participant data, and no individual-level results were shared with employers. Data were stored securely in accordance with international ethical guidelines for human subjects' research and applicable data protection regulations.

The voluntary nature of participation and adherence to ethical standards ensured respect for autonomy, beneficence, and non-maleficence. These procedures align with international research ethics principles governing psychological and occupational health studies, particularly when assessments involve cognitive testing and psychosocial evaluation in workplace settings. Collectively, the participant selection and ethical procedures strengthened the

internal validity of the study while preserving ecological relevance and participant protection.

3.3 Group allocation and training conditions

Participants were assigned to one of three structured conditions: (1) a Cognitive-Behavioral Stress Management Program (STR), (2) a Salutogenetic Health Promotion Program focused on sense of coherence (SOC), and (3) a wait-list control group. Allocation was organized to ensure balanced representation across groups while maintaining the ecological integrity of the occupational context. Although the broader research project incorporated structured training interventions, the primary analytical emphasis of this chapter remains correlational. Specifically, the study examines relational patterns among occupational stress, psychological resources, executive functioning, cognitive workload, and well-being indicators across and within these contexts, rather than evaluating intervention efficacy in a strictly causal framework. The inclusion of parallel training conditions provides a theoretically meaningful comparative backdrop for analyzing how cognitive-behavioral and salutogenetic orientations relate to patterns of stress perception, burnout, and cognitive performance in industrial workers.

The Cognitive-Behavioral Stress Management (STR) program was grounded in transactional stress theory and cognitive-behavioral principles, particularly the framework advanced by Lazarus and Folkman (1984), which conceptualizes stress as a function of cognitive appraisal processes. According to this perspective, stress responses are not determined solely by objective external demands but are mediated by individuals' interpretations, beliefs, and perceived coping capacities. Contemporary occupational applications of cognitive-behavioral stress management further emphasize the modification of maladaptive thought patterns to reduce psychological strain and enhance executive regulation (Zhang et al., 2023). Within this theoretical foundation, the STR program included psychoeducation on physiological and psychological mechanisms of stress, enabling participants to understand the interaction between cognitive appraisal, autonomic activation, and emotional responses. Participants were guided in identifying dysfunctional automatic thoughts, such as catastrophizing, overgeneralization, and negative self-evaluations, which may amplify perceived occupational demands. Structured cognitive restructuring techniques were introduced to facilitate the replacement of maladaptive cognitions with more balanced and adaptive interpretations. Behavioral stress-reduction strategies were also incorporated, including time management principles, problem-solving frameworks, and adaptive coping rehearsal. Additionally, Progressive Muscle Relaxation (PMR) was systematically practiced to reduce physiological arousal and promote autonomic regulation, thereby supporting cognitive clarity and attentional stability. Cognitive-behavioral stress management programs have demonstrated effectiveness in reducing perceived stress, improving emotional regulation, and supporting executive functioning in occupational populations, reinforcing the theoretical rationale for its inclusion in the present design (Zhang et al., 2023).

The Salutogenetic Health Promotion Program was based on the theoretical construct of sense of coherence (SOC), originally conceptualized by Aaron Antonovsky and further elaborated in contemporary salutogenesis research (Mittelmark et al., 2022). Unlike pathogenic models that focus primarily on symptom reduction, the salutogenetic perspective emphasizes the strengthening of personal resources that promote health and resilience. Within this framework, sense of coherence comprises three core components: comprehensibility, manageability, and meaningfulness. The intervention was designed to strengthen comprehensibility by helping participants develop structured and coherent understandings of occupational stressors, thereby reducing uncertainty and cognitive fragmentation. Manageability was addressed through exercises aimed at identifying existing personal and organizational resources, reinforcing perceived coping capacity and problem-solving competence. Meaningfulness was cultivated by encouraging reflection on professional purpose, personal values, and engagement with work-related challenges as opportunities for growth rather than solely as burdens. Salutogenic approaches emphasize resource activation, adaptive orientation, and resilience development rather than direct symptom suppression, and have been associated with enhanced occupational well-being, stronger psychological resilience, and lower burnout levels in working populations (Super et al., 2021).

Both training conditions consisted of eight structured group sessions delivered in a standardized format to ensure consistency across cohorts. Each session combined theoretical instruction with experiential learning components. Theoretical segments introduced core conceptual principles, including stress physiology, appraisal mechanisms, coping strategies, and resource orientation. Guided exercises facilitated the practical application of these concepts to real occupational scenarios encountered by industrial workers. Interactive discussions promoted peer reflection and normalization of stress experiences, fostering a collaborative learning environment. Applied coping practice sessions allowed participants to rehearse cognitive restructuring, relaxation techniques, and resource-based reframing in simulated or real workplace situations. The use of parallel session structures ensured comparability in duration, contact time, and group interaction across both intervention conditions, while preserving their distinct theoretical emphases—cognitive restructuring and stress regulation in the STR condition, and resource strengthening and coherence-building in the SOC-focused condition.

The wait-list control group did not receive structured training during the assessment period but participated in identical pre- and post-assessment procedures. This condition provided a naturalistic reference for examining relational patterns independent of structured intervention exposure. Importantly, the inclusion of a wait-list group was designed not primarily to test efficacy but to preserve methodological rigor in comparing associative patterns across contexts.

Overall, the group allocation and structured training conditions were designed to reflect two complementary theoretical traditions within occupational health psychology, cognitive-behavioral and salutogenetic, while maintaining the correlational and multivariate analytical focus of the study. This design enables examination of how differing theoretical orientations may be associated with distinct patterns of stress perception, executive functioning, cognitive workload, burnout

dimensions, and occupational well-being within contemporary industrial environments.

3.4 Measures and instruments

3.4.1 Cognitive assessments

Cognitive performance was evaluated using a comprehensive battery of standardized neuropsychological instruments designed to assess core domains directly relevant to safe and efficient industrial performance. The selection of measures was guided by contemporary cognitive stress research indicating that occupational stress most consistently affects attentional regulation, working memory capacity, executive control, cognitive flexibility, and psychomotor processing speed (Shields et al., 2020; Starcke and Brand, 2022). Given that modern industrial tasks frequently require sustained vigilance, rapid information processing, task switching, inhibitory control, and accurate motor responses, these domains were considered essential for evaluating the functional cognitive impact of occupational stress and psychological resources.

Attention was assessed using the d2 Test of Attention and the Test of Attentional Performance (TAP). The d2 Test is a widely used paper-and-pencil cancellation task measuring selective attention, concentration performance, and processing speed under time pressure, with recent research confirming its reliability, construct validity, and sensitivity to attentional control variations in adult populations (Steinborn et al., 2022). The TAP, a computerized neuropsychological battery, allows precise assessment of sustained and divided attention through reaction-time-based paradigms and has demonstrated strong psychometric stability and applicability in executive-attentional monitoring research (Lindner et al., 2021). The combined use of these instruments enabled evaluation of attentional efficiency across continuous performance and stimulus discrimination conditions, reflecting real-world industrial demands requiring prolonged monitoring and rapid response to critical signals.

Memory functioning was examined using Digit Span Forward and Backward tasks and a standardized Verbal Learning and Memory Test. Digit Span Forward primarily assesses short-term storage capacity and attentional span, whereas Digit Span Backward requires active manipulation of information, indexing working memory and executive updating processes. Contemporary psychometric evaluations support the continued reliability and executive sensitivity of Digit Span measures in adult cognitive assessment (Schutte et al., 2020). Verbal learning paradigms assessing acquisition across trials, delayed recall, and recognition have demonstrated strong ecological validity and reliability in measuring encoding and retrieval processes under cognitively demanding conditions (Calamia et al., 2021). These memory components are particularly relevant in industrial settings where workers must retain procedural instructions, adapt to changing operational parameters, and integrate new technical information under time constraints.

Executive functions were measured using the Stroop Color–Word Test and the Trail Making Test (TMT) Parts A and B. The Stroop task assesses inhibitory control and cognitive interference resolution by requiring suppression of automatic reading

responses in favor of color naming and remains a gold-standard measure of executive control, with updated methodological and neurocognitive validation evidence supporting its robustness (Scarpina & Tagini, 2020; Varjadic et al., 2022). TMT Part A evaluates visual scanning and psychomotor speed, whereas Part B assesses cognitive flexibility and set-shifting ability. Recent normative and reliability studies confirm the TMT's continued construct validity for executive functioning and processing speed in adult samples (Rabin et al., 2021). Together, these instruments capture central executive processes linked to adaptive decision-making and performance regulation under stress.

Psychomotor speed was assessed using the Digit Symbol Substitution Test (DSST), a sensitive measure of processing speed, visual-motor coordination, and incidental learning. The DSST has demonstrated high sensitivity to stress-related cognitive slowing and executive inefficiency, with contemporary reviews highlighting its strong psychometric properties and broad applicability in performance-based research (Jaeger, 2021; Knowles et al., 2023). Psychomotor efficiency is critical in industrial environments where rapid yet accurate responses to machine interfaces and environmental cues are required.

The selection of these cognitive domains is theoretically supported by neurocognitive evidence demonstrating that stress-related activation of the hypothalamic-pituitary-adrenal (HPA) axis and elevated cortisol levels may compromise prefrontal cortical functioning, thereby affecting executive control, attentional stability, and working memory capacity (Shields et al., 2020). Furthermore, decision-making under stress has been shown to shift toward more rigid and less flexible cognitive patterns, reinforcing the importance of executive function assessment in occupational populations (Starcke & Brand, 2022). By evaluating attention, memory, executive processes, and psychomotor speed simultaneously, the present battery provides a multidimensional representation of cognitive performance relevant to industrial task demands.

To minimize potential practice effects associated with repeated cognitive testing, parallel forms were administered when available. Contemporary meta-analytic evidence supports the importance of alternate forms in reducing learning effects and preserving internal validity in repeated-measures neuropsychological designs (Calamia et al., 2021). Standardized administration protocols were strictly followed to ensure reliability across assessment sessions.

The objective cognitive assessment battery was designed to capture stress-sensitive domains of cognitive functioning critical for operational safety, decision accuracy, and adaptive performance in industrial settings. The integration of these standardized measures with psychosocial assessments enables robust examination of relationships among occupational stress, psychological resources, executive functioning, and work-related well-being.

3.4.2 Psychosocial and occupational measures

Validated self-report instruments were used to assess psychosocial constructs relevant to occupational stress, cognitive functioning, and work-related well-being.

Perceived stress was measured using the Perceived Stress Questionnaire (PSQ-20), which evaluates subjective stress perception across domains such as tension, worries, demands, and lack of joy. Recent psychometric evaluations confirm the PSQ-20's factorial validity, internal consistency, and cross-cultural applicability in occupational populations (Fliege et al., 2021; Levenstein et al., 2023). The instrument captures stress appraisal processes that are central to cognitive strain and executive vulnerability under prolonged occupational demands.

Salutogenic resource orientation was assessed using the Sense of Coherence Scale (SOC). The SOC measures comprehensibility, manageability, and meaningfulness, core components of adaptive stress regulation. Contemporary research continues to support the SOC's construct stability and predictive validity for psychological resilience, work engagement, and health outcomes in occupational samples (Eriksson and Mittelmark, 2022; Super et al., 2021). Higher sense of coherence has been associated with improved stress modulation and cognitive performance stability.

Burnout symptoms were measured using the Maslach Burnout Inventory (MBI), assessing emotional exhaustion, depersonalization, and reduced professional efficacy. The MBI remains the most widely validated instrument for occupational burnout assessment. Recent theoretical refinements emphasize burnout as a work-related syndrome emerging from chronic unmanaged stress, with emotional exhaustion identified as its central component (Maslach and Leiter, 2021). Empirical findings demonstrate consistent associations between emotional exhaustion and impairments in executive functioning, attentional regulation, and cognitive flexibility (Deligkaris et al., 2023). These findings justify the inclusion of burnout dimensions within models examining stress-related cognitive outcomes.

Perceived every day, cognitive lapses were assessed using the Cognitive Failures Questionnaire (CFQ). The CFQ captures self-reported attentional slips, memory failures, and action errors occurring in daily activities. Recent research confirms its reliability and sensitivity to stress, fatigue, and occupational overload, supporting its relevance in applied cognitive and workplace research (Carrigan & Barkus, 2021; Bufano et al., 2024). The CFQ provides a subjective complement to performance-based cognitive testing.

Perceived occupational functioning was measured using the Work Ability Index (WAI), which evaluates workers' self-perceived capacity to meet job demands relative to health status and functional resources. Contemporary occupational health research continues to support WAI's predictive validity for absenteeism, productivity, and long-term work participation (Ilmarinen, 2022; Cadiz et al., 2021). Work ability has also been linked to psychological resilience and cognitive performance under stress.

Burnout dimensions were included due to established associations between emotional exhaustion and impaired executive functioning, decision-making inefficiency, and reduced attentional control (Maslach & Leiter, 2021; Deligkaris et al., 2023). The inclusion of both objective cognitive measures and subjective cognitive failure reports reflects contemporary methodological recommendations emphasizing multidimensional cognitive assessment frameworks in occupational research (Bufano et al., 2024). Integrating self-perceived cognitive functioning with

standardized neuropsychological testing enhances ecological validity and allows for a more comprehensive understanding of stress-related performance variability.

3.5 Data analysis

3.5.1 Preliminary analyses

Prior to testing the main hypotheses, preliminary analyses were conducted to examine sample characteristics and assess the suitability of the data for parametric analyses. Descriptive statistics, including means, standard deviations, ranges, skewness, and kurtosis, were computed for all psychosocial and cognitive measures to characterize central tendency and variability within the sample. These descriptive indices provided an initial understanding of participant distributions, highlighting potential floor or ceiling effects and informing the interpretation of subsequent analyses.

Assumptions of normality, linearity, and homoscedasticity were evaluated through visual inspection of histograms, Q-Q plots, and scatterplots. Skewness and kurtosis values were examined against recommended thresholds for normality in social science research (West et al., 2020). Scatterplots of paired variables were inspected to confirm linear relationships, which is critical for valid interpretation of correlational and regression analyses (Osborne and Overbay, 2021). These diagnostics are consistent with best practices in occupational and cognitive research, ensuring that parametric procedures, including Pearson correlations and multiple regression, provide reliable and interpretable estimates of relationships among occupational stress, cognitive functioning, burnout, and work ability (Spector, 2022).

Where minor deviations from normality were observed, sensitivity analyses were planned to verify that results were robust to non-normal distributions. This approach aligns with contemporary recommendations emphasizing rigorous preliminary data screening as a prerequisite for valid multivariate and correlational modeling in occupational health research (Kline, 2022).

3.5.2 Correlational analyses

Bivariate relationships among key study variables were examined using Pearson's product-moment correlation coefficient (r). Specifically, correlations were calculated between perceived stress (PSQ-20), sense of coherence (SOC), burnout dimensions (emotional exhaustion, depersonalization, reduced professional efficacy), cognitive failures (CFQ), work ability (WAI), and objective cognitive performance indicators (attention, working memory, executive function, and psychomotor speed). Pearson correlations were selected because all variables were continuous, and the primary aim was to identify the direction, magnitude, and statistical significance of associations among psychosocial and cognitive domains.

The use of Pearson correlation is supported by contemporary occupational and cognitive research as a robust method for examining linear relationships between stress, cognitive performance, and work-related well-being (Spector, 2022; West et

al., 2020). Prior to analysis, assumptions of linearity, homoscedasticity, and normality were evaluated through visual inspection of scatterplots and distribution statistics to ensure the appropriateness of parametric testing (Osborne and Overbay, 2021). Interpreting correlation coefficients allowed for identification of patterns such as negative associations between stress and cognitive performance or positive associations between sense of coherence and work ability, which provide empirical insight into potential mediating or moderating mechanisms for subsequent multivariate analyses.

Effect sizes were interpreted according to conventional benchmarks for behavioral sciences (Cohen, 1988), with small ($r \approx 0.10$), medium ($r \approx 0.30$), and large ($r \approx .50$) effects used as reference points to assess the practical significance of observed relationships in occupational contexts.

5.3.3 Multiple regression analyses

To examine the multivariate relationships between psychosocial factors and cognitive functioning, multiple linear regression models were specified with cognitive outcomes, specifically attention and executive function measures, as dependent variables. Independent predictors included perceived stress (PSQ-20), emotional exhaustion (MBI), sense of coherence (SOC), and work ability (WAI). This analytical approach allows for the evaluation of the unique contribution of each predictor while controlling for shared variance among other variables, thereby providing insight into the relative predictive strength of psychosocial resources and stress-related factors on cognitive performance (Spector, 2022; Kline, 2022).

Standardized beta coefficients (β) were reported to facilitate comparison of effect magnitudes across predictors, while overall model fit was assessed through explained variance (R^2) and F-statistics. Statistical significance was evaluated using two-tailed tests with an alpha level of $p < .05$. Prior to model estimation, multicollinearity diagnostics, including variance inflation factors (VIF) and tolerance statistics, were examined to ensure that independent predictors did not violate assumptions of independence (Osborne & Overbay, 2021). Residual plots and Q-Q plots were inspected to verify assumptions of homoscedasticity and normality of errors.

Because the study employed a non-experimental, correlational design, regression results were interpreted strictly as associative relationships rather than causal effects. This approach aligns with contemporary occupational cognitive research emphasizing multivariate modeling as a method to identify predictive patterns and potential risk factors for cognitive impairment under occupational stress while avoiding overinterpretation of causality (West et al., 2020; Shields et al., 2020).

4.1 RESULTS

4.1 Preliminary analyses

Descriptive statistics for all psychosocial and cognitive variables are presented in Table 1. The sample of 200 industrial workers demonstrated a wide range of perceived stress scores (PSQ-20 Mean = 46.7, SD = 12.3), sense of coherence levels (SOC Mean = 64.2, SD = 9.8), burnout dimensions (emotional exhaustion Mean = 21.5, SD = 8.7; depersonalization Mean = 7.3, SD = 3.9; reduced professional efficacy Mean = 15.1, SD = 5.4), cognitive failures (CFQ Mean = 36.8, SD = 10.2), and work ability (WAI M = 38.5, SD = 6.4). Objective cognitive measures revealed mean performance scores within normative ranges for adult industrial populations, including attention indices (d2 Test CP M = 183.5, SD = 24.2; TAP reaction time Mean = 412 ms, SD = 58), working memory (Digit Span Forward Mean = 9.1, SD = 1.5; Backward Mean = 7.6, SD = 1.4), executive function (Stroop interference Mean = 42.3 s, SD = 10.5; TMT Part B Mean = 57.2 s, SD = 15.7), and psychomotor speed (DSST Mean = 74.1, SD = 12.6).

Visual inspection of histograms and Q-Q plots indicated approximate normality across psychosocial and cognitive measures. Skewness and kurtosis values were within acceptable thresholds (± 2.0), confirming the suitability of parametric analyses (West et al., 2020). Scatterplots demonstrated linear relationships between key predictor and outcome variables, supporting the use of Pearson correlations and multiple regression models (Osborne and Overbay, 2021). No extreme outliers or violations of homoscedasticity were observed, providing confidence in the stability of subsequent analyses.

4.2 Correlational analyses

Pearson correlation analyses examined bivariate associations among perceived stress, sense of coherence, burnout dimensions, cognitive failures, work ability, and objective cognitive performance (Table 2).

Perceived stress (PSQ-20) was negatively correlated with attention (d2 CP $r = -0.38$, $p < 0.001$; TAP sustained attention $r = -0.32$, $p < 0.001$), working memory (Digit Span Backward $r = -0.29$, $p < 0.001$), and executive function (Stroop interference $r = 0.31$, $p < 0.001$; TMT Part B $r = 0.27$, $p < 0.001$), indicating that higher subjective stress was associated with slower performance and greater interference susceptibility. Stress also correlated positively with burnout dimensions, particularly emotional exhaustion ($r = .56$, $p < .001$), and with cognitive failures (CFQ $r = 0.49$, $p < .001$), consistent with stress-related attentional lapses and executive strain.

Sense of coherence (SOC) exhibited positive correlations with attention (d2 CP $r = 0.33$, $p < 0.001$; TAP $r = 0.29$, $p < 0.001$), working memory (Digit Span Backward $r = 0.25$, $p < 0.01$), and psychomotor speed (DSST $r = 0.21$, $p < 0.01$), as well as a negative association with emotional exhaustion ($r = -0.41$, $p < 0.001$) and cognitive failures ($r = -0.35$, $p < 0.001$). These patterns suggest that stronger salutogenic resources buffer the cognitive impact of occupational stress.

Burnout dimensions revealed domain-specific correlations with cognitive outcomes. Emotional exhaustion was negatively associated with attention and executive function (r range: -0.27 to -0.38 , $p < 0.001$), whereas depersonalization showed weaker but significant associations with cognitive failures ($r = 0.21$, $p < 0.01$). Reduced professional efficacy demonstrated moderate negative associations with work ability ($r = -0.46$, $p < 0.001$) and attention measures ($r = -0.19$ to -0.23 , $p < 0.05$).

Cognitive failures (CFQ) were consistently negatively correlated with all objective cognitive measures, most strongly with attention (d2 CP $r = -0.42$, $p < 0.001$) and executive function (TMT Part B $r = 0.35$, $p < 0.001$), confirming the alignment between self-reported lapses and laboratory-based cognitive performance.

Work ability (WAI) was positively correlated with attention (d2 CP $r = 0.31$, $p < 0.001$), working memory (Digit Span Forward $r = 0.28$, $p < 0.01$), and psychomotor speed (DSST $r = 0.24$, $p < 0.01$), while inversely associated with perceived stress ($r = -0.39$, $p < 0.001$) and emotional exhaustion ($r = -0.52$, $p < 0.001$). These correlations highlight the interplay between subjective functional capacity, psychosocial strain, and cognitive performance in occupational settings.

Effect size interpretation indicated **medium to large effects** for the strongest associations (e.g., stress–emotional exhaustion, $r = 0.56$; Cohen, 1988), and small-to-medium effects for cognitive correlates, consistent with prior literature on occupational stress and executive functioning (Shields et al., 2020; Starcke and Brand, 2022).

4.3 Multiple regression analyses

Multiple linear regression analyses were conducted to examine **unique contributions of psychosocial predictors** on objective cognitive outcomes. Separate models were estimated for attention (d2 CP), working memory (Digit Span Backward), and executive function (Stroop interference, TMT Part B) as dependent variables.

Attention (d2 CP): The regression model including perceived stress, emotional exhaustion, sense of coherence, and work ability was significant, $F(4,195) = 18.7$, $p < 0.001$, $R^2 = 0.28$. Standardized coefficients indicated that perceived stress ($\beta = -0.26$, $p < 0.001$) and sense of coherence ($\beta = 0.21$, $p = 0.002$) were the strongest unique predictors of attentional performance, while emotional exhaustion ($\beta = -0.14$, $p = 0.045$) contributed modestly. Work ability was not a significant independent predictor in this model ($\beta = 0.09$, $p = 0.12$).

Working memory (Digit Span Backward): The model was significant, $F(4,195) = 12.3$, $p < 0.001$, $R^2 = 0.20$. Perceived stress ($\beta = -0.23$, $p = 0.001$) and sense of coherence ($\beta = 0.18$, $p = 0.007$) were significant predictors, whereas emotional exhaustion and work ability did not reach significance.

Executive function (Stroop interference): The model demonstrated significant explanatory power, $F(4,195) = 15.5$, $p < 0.001$, $R^2 = 0.24$. Perceived stress ($\beta = 0.28$, $p < 0.001$) and emotional exhaustion ($\beta = 0.17$, $p = 0.011$) predicted slower

interference resolution, whereas sense of coherence was associated with faster performance ($\beta = -0.19$, $p = 0.005$).

Executive function (TMT Part B): The regression model was significant, $F(4,195) = 11.8$, $p < 0.001$, $R^2 = 0.19$. Perceived stress ($\beta = 0.22$, $p = 0.002$) and emotional exhaustion ($\beta = 0.16$, $p = 0.021$) were the strongest predictors of slower completion times, and sense of coherence again contributed positively ($\beta = -0.15$, $p = 0.038$). Multicollinearity diagnostics indicated acceptable VIF values (<2.0), and residual plots confirmed normality and homoscedasticity of errors.

These multivariate analyses confirm that **perceived stress and burnout-related emotional exhaustion are consistently associated with poorer cognitive performance**, while sense of coherence acts as a protective factor. Work ability demonstrated more modest associations, primarily mediated by stress and burnout levels. Importantly, because the study was correlational, these findings indicate **associative patterns rather than causal relationships**, reflecting complex interdependencies between psychosocial factors and cognitive outcomes in industrial workers.

The present study revealed several noteworthy patterns in the relationships among occupational stress, psychosocial resources, and cognitive functioning in industrial workers. Descriptive analyses indicated that participants experienced moderate levels of perceived stress and burnout, particularly in the domain of emotional exhaustion, while interindividual variability in objective cognitive performance was substantial, reflecting diverse attentional, executive, and memory capacities across the sample. Bivariate correlation analyses demonstrated robust associations between perceived stress, emotional exhaustion, and self-reported cognitive failures, which were mirrored by objective deficits in attention, working memory, and executive function. Conversely, a higher sense of coherence consistently showed protective associations, buffering the negative impact of stress and burnout on cognitive performance. Multivariate regression models further confirmed that perceived stress and emotional exhaustion were significant negative predictors of attentional capacity and executive functioning, while sense of coherence emerged as a consistent positive predictor, underscoring the importance of salutogenic resources for cognitive resilience in occupational contexts. Integration of subjective and objective measures revealed a close alignment between self-reported cognitive failures and laboratory-based assessments of attention and executive function, supporting the use of multidimensional assessment approaches that combine performance-based and perceptual indicators of cognitive functioning. Taken together, these findings highlight the complex, multidimensional interplay between occupational stress, psychological resources, and cognitive functioning, emphasizing the relevance of both cognitive-behavioral and salutogenic frameworks in understanding mechanisms of resilience and vulnerability among industrial workers, as well as informing the design of interventions aimed at mitigating stress-related cognitive impairments in workplace settings.

The present study provided a comprehensive examination of the relationships among occupational stress, psychosocial resources, and cognitive functioning in industrial workers, integrating both objective neuropsychological assessments and self-reported measures of cognitive failures and well-being. The findings contribute

to a growing body of evidence emphasizing the multidimensional nature of cognitive and psychosocial functioning in high-demand work environments. Overall, the results highlight how perceived stress and burnout, particularly emotional exhaustion, are associated with decrements in attention, executive control, working memory, and psychomotor efficiency, while sense of coherence serves as a protective factor that promotes cognitive resilience and supports occupational well-being.

The observed moderate levels of perceived stress and burnout align with prior studies in industrial contexts, where high cognitive demands, time pressure, and exposure to complex machinery contribute to psychological strain (Shields et al., 2020; Starcke & Brand, 2022). Bivariate analyses indicated strong associations between stress, emotional exhaustion, and self-reported cognitive failures, which were reflected in objective cognitive deficits, supporting the notion that occupational stress not only affects subjective experience but also manifests in measurable performance decrements. These findings corroborate theoretical perspectives emphasizing the central role of cognitive appraisal and resource availability in moderating stress outcomes (Lazarus and Folkman, 1984; Zhang et al., 2023).

Multivariate regression models further elucidated these dynamics by demonstrating that perceived stress and emotional exhaustion are significant negative predictors of attentional efficiency and executive function. This indicates that high stress and burnout levels may impair workers' ability to maintain sustained attention, inhibit prepotent responses, and engage in flexible problem-solving—cognitive capacities critical for safe and efficient industrial performance. Conversely, sense of coherence consistently predicted better performance across attentional and executive domains, emphasizing the salutogenic principle that strengthening personal resources enhances adaptive cognitive functioning under stress (Eriksson and Mittelman, 2022; Super et al., 2021). These results underscore the theoretical complementarity of cognitive-behavioral and salutogenic approaches: while stress management programs target the reduction of maladaptive cognitive and emotional patterns, resource-oriented interventions foster resilience and meaning-making, both of which contribute to sustained cognitive performance in demanding work environments.

The alignment observed between subjective cognitive failures (CFQ scores) and objective cognitive performance measures provides empirical support for the integration of self-report and performance-based assessment approaches. Workers' perceptions of attentional lapses, memory errors, and executive difficulties appear to reflect actual performance limitations, suggesting that multidimensional evaluation frameworks enhance ecological validity and offer actionable insights for workplace interventions (Bufano et al., 2024; Carrigan and Barkus, 2021). This finding also implies that organizations can rely on carefully validated self-report tools as cost-effective indicators of cognitive risk, complementing periodic objective assessment when monitoring cognitive safety and work ability.

From a practical perspective, the study highlights the importance of designing occupational health interventions that address both stress reduction and resource enhancement. Cognitive-behavioral strategies, such as cognitive restructuring, problem-solving, and relaxation training, can mitigate the detrimental effects of

stress on attentional and executive processes. Simultaneously, fostering sense of coherence through structured reflection on meaning, manageability, and comprehensibility may strengthen cognitive resilience, buffer against burnout, and support adaptive decision-making in complex industrial tasks. Integrating these complementary approaches may provide a more holistic model for promoting cognitive health and occupational well-being.

Limitations of the study should be acknowledged. First, the correlational design precludes causal inference, meaning that observed associations cannot definitively determine whether stress causes cognitive impairment or vice versa.

Second, although the sample was relatively large and diverse within industrial contexts, findings may not generalize to non-industrial or highly specialized occupational populations.

Third, self-report instruments, while validated and reliable, may be subject to social desirability or recall biases. Finally, while parallel forms of cognitive tests reduced practice effects, repeated assessments may still introduce subtle learning or motivational influences.

Future research should aim to employ longitudinal or experimental designs to clarify causal pathways between occupational stress, psychological resources, and cognitive performance. Intervention studies combining cognitive-behavioral and salutogenic frameworks could examine whether enhancing sense of coherence amplifies the efficacy of stress management programs in preserving attention, executive functioning, and psychomotor efficiency over time. Additionally, integrating physiological measures of stress (e.g., cortisol, heart rate variability) alongside cognitive and psychosocial indicators could further illuminate the mechanisms linking stress exposure to cognitive outcomes.

In conclusion, the findings of this study underscore the complex, multidimensional interplay between occupational stress, psychological resources, and cognitive functioning in industrial workers. Perceived stress and emotional exhaustion compromise attention, executive control, and psychomotor performance, whereas sense of coherence serves as a protective factor promoting resilience. These results provide empirical support for integrating cognitive-behavioral and salutogenic frameworks in workplace interventions and highlight the value of multidimensional assessment strategies that combine objective cognitive testing with self-reported cognitive experiences. By addressing both risk factors and protective resources, organizations can better support cognitive health, adaptive performance, and overall occupational well-being in high-demand industrial settings.

While the present study provides valuable insights into the interplay between occupational stress, psychological resources, and cognitive functioning in industrial workers, several limitations must be acknowledged. First, the correlational, non-experimental design precludes causal inference.

Although the analyses reveal strong associations between perceived stress, emotional exhaustion, sense of coherence, and cognitive performance, it cannot be concluded that stress directly causes cognitive impairment or that enhancing sense of coherence will automatically improve attentional or executive functioning. Temporal or bidirectional effects may exist, as cognitive difficulties could also contribute to heightened stress perception or burnout symptoms.

Second, the study relied on a single measurement occasion for each pre- and post-assessment period, which may not fully capture fluctuations in stress levels, cognitive performance, or well-being over longer occupational cycles. Daily or ecological momentary assessment approaches could provide more granular insights into dynamic relationships and transient stress-related cognitive impairments.

Third, although the sample size was substantial ($n = 200$) and recruited from diverse industrial sectors, generalizability may be limited to similar occupational contexts. Findings may not extend to highly specialized industrial roles, non-industrial workplaces, or populations with differing cultural, organizational, or socioeconomic characteristics.

Fourth, self-report measures, including the Perceived Stress Questionnaire (PSQ-20), Cognitive Failures Questionnaire (CFQ), Maslach Burnout Inventory (MBI), and Sense of Coherence Scale (SOC), are subject to potential biases such as social desirability, response style, or recall inaccuracies. Although these instruments are psychometrically validated and widely used, they may not fully capture real-time cognitive lapses or stress experiences.

Fifth, despite the use of standardized cognitive assessments with parallel forms to minimize practice effects, repeated testing may still introduce subtle learning, motivation, or fatigue influences that could affect performance outcomes. Psychophysiological measures of stress or objective work performance indicators could complement neuropsychological testing to provide convergent evidence of cognitive functioning under occupational stress.

Finally, while the study examined multiple psychosocial and cognitive variables, unmeasured confounding factors, such as sleep quality, physical health, workplace environmental conditions, or personal life stressors, may have influenced cognitive performance and perceived well-being. Future research should consider these contextual and lifestyle factors to provide a more comprehensive understanding of occupational cognitive resilience and vulnerability.

While the study offers robust evidence on the multidimensional relationships among stress, resources, and cognition, these limitations suggest caution in interpreting findings as causal, and highlight the need for longitudinal, multi-method, and ecologically valid research to fully elucidate the mechanisms underlying occupational cognitive functioning.

5. CONCLUSIONS

The present study provides a comprehensive examination of the complex relationships among occupational stress, psychological resources, and cognitive functioning in industrial workers. Findings indicate that perceived stress and emotional exhaustion are consistently associated with decreased attentional efficiency, impaired executive functioning, and slower psychomotor performance, highlighting the vulnerability of core cognitive domains to workplace demands and psychosocial strain. Conversely, sense of coherence emerges as a robust protective factor, positively predicting attentional and executive outcomes and buffering the negative effects of stress and burnout.

Integration of objective cognitive assessments with self-reported measures of cognitive failures underscores the value of multidimensional evaluation approaches, as subjective experiences of lapses closely align with laboratory-based performance indicators. This alignment reinforces the ecological validity of combining performance-based and self-report methods for monitoring cognitive health in industrial contexts.

The findings further support the theoretical complementarity of cognitive-behavioral and salutogenetic frameworks. Cognitive-behavioral approaches address maladaptive thought patterns and enhance coping strategies, while salutogenetic principles strengthen personal resources, meaning-making, and resilience. Together, these perspectives offer a holistic understanding of cognitive vulnerability and adaptive potential in high-demand occupational settings.

Overall, the study highlights the importance of assessing and supporting both psychosocial resources and cognitive capacities in industrial workers. Interventions targeting stress reduction, resource strengthening, and attention-executive resilience may contribute to improved occupational well-being, enhanced decision-making, and safer, more efficient work performance. The results provide a strong empirical foundation for designing integrated workplace programs that address both risk factors and protective mechanisms, emphasizing the need for ongoing, multidimensional assessment and targeted intervention in contemporary industrial environments.

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QUANTITATIVE EVALUATION OF VISUAL LOAD IN DIGITAL INTERFACES USING COLORIMETRIC ANALYSIS AND VISUAL CONDITION SIMULATION FROM AN OCCUPATIONAL ERGONOMICS APPROACH

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Resumen Este proyecto propone el desarrollo del Índice de Carga Visual (ICV), un modelo heurístico que integra parámetros de colorimetría para estimar el riesgo visual en interfaces digitales. Mediante el uso de la aplicación ICV Analyzer, se miden variables como saturación, contraste (WCAG 2.1), brillo y tono, permitiendo identificar riesgos ergonómicos cuantitativos. Los resultados demuestran que paletas optimizadas reducen el ICV entre un 30% y 60%. Además, el sistema incluye simulaciones de miopía y astigmatismo para evaluar la accesibilidad real en usuarios con limitaciones perceptuales.

La investigación propone la creación del Índice de Carga Visual (ICV), un modelo que cuantifica el nivel de exigencia visual en entornos digitales mediante parámetros objetivos como luminancia, contraste, saturación, temperatura de color, distribución cromática y relaciones figura-fondo. Además, incorpora simulaciones de condiciones visuales frecuentes en contextos laborales (fatiga visual, baja agudeza, alteraciones en la percepción del color y exposición prolongada a pantallas), permitiendo estimar el riesgo ergonómico asociado al diseño de interfaces.

Metodológicamente, el estudio combina análisis instrumental de colorimetría digital con pruebas experimentales en usuarios, utilizando métricas fisiológicas y perceptuales para correlacionar los valores del ICV con indicadores de fatiga visual y desempeño cognitivo.

El impacto ergonómico del proyecto radica en su contribución a la prevención de trastornos visuales asociados al trabajo con pantallas (como el síndrome de visión por computadora), la optimización del confort visual y la mejora del rendimiento laboral. Además, aporta un modelo innovador y medible para evaluar la carga visual en interfaces digitales, fortaleciendo la relación entre diseño tecnológico y salud ocupacional, y promoviendo entornos digitales más seguros, accesibles y sostenibles desde la perspectiva ergonómica.

Palabras clave: Carga visual, colorimetría, ergonomía visual, ICV, diseño de interfaces.

Relevancia para la ergonomía: Este artículo es fundamental porque ofrece un modelo cuantitativo preventivo que permite a los diseñadores ir más allá de la estética, alineándose con normativas como la NOM-036-1-STPS-2018 para proteger la salud ocular de los trabajadores.

Uno de los principales propósitos de este proyecto es desarrollar y validar un modelo cuantitativo para evaluar la carga visual generada por interfaces digitales, integrando análisis colorimétrico y simulación de condiciones visuales desde un enfoque de ergonomía ocupacional.

Abstract: This project proposes the development of the Visual Load Index (VLI), a heuristic model that integrates colorimetric parameters to estimate visual risk in digital interfaces. By using the ICV Analyzer application, variables such as saturation, contrast (WCAG 2.1), brightness, and hue are measured, allowing for the identification of quantitative ergonomic risks. The results demonstrate that optimized palettes reduce the VLI by 30% to 60%. Additionally, the system includes simulations of myopia and astigmatism to evaluate real accessibility for users with perceptual limitations.

The research proposes the creation of the Visual Load Index (VLI), a model that quantifies the level of visual demand in digital environments using objective parameters such as luminance, contrast, saturation, color temperature, color distribution, and figure-ground relationships. It also incorporates simulations of visual conditions frequently encountered in work contexts (visual fatigue, low acuity, alterations in color perception, and prolonged exposure to screens), allowing for the estimation of ergonomic risks associated with interface design.

Methodologically, the study combines instrumental analysis of digital colorimetry with experimental tests on users, using physiological and perceptual metrics to correlate ICV values with indicators of visual fatigue and cognitive performance.

The ergonomic impact of the project lies in its contribution to the prevention of visual disorders associated with working with screens (such as computer vision syndrome), the optimization of visual comfort, and the improvement of work performance. In addition, it provides an innovative and measurable model for assessing visual load in digital interfaces, strengthening the relationship between technological design and occupational health, and promoting safer, more accessible, and more sustainable digital environments from an ergonomic perspective.

Keywords. Visual load, colorimetry, visual ergonomics, VLI, interface design.

Relevance to Ergonomics: This article provides an innovative quantitative model to prevent visual fatigue in digital environments. It aligns with international standards and Mexican regulations like NOM-036-1-STPS-2018, offering a practical tool to identify and control ergonomic risk factors in digital workplaces.

1. INTRODUCTION

The increasing dependence on digital interfaces across occupational, educational, and daily environments has generated growing concern regarding visual fatigue and perceptual overload. Prolonged exposure to screens has been associated with symptoms such as ocular discomfort, blurred vision, headaches, decreased concentration, and reduced task performance. These effects, commonly grouped under Computer Vision Syndrome (CVS), represent an emerging ergonomic challenge in modern digital work environments (Pachón Robles et al., 2022).

Global prevalence estimates indicate that CVS affects a substantial proportion of digital device users. A recent systematic review and meta-analysis reported that the prevalence of Computer Vision Syndrome is approximately 69 % (95 % CI: 62.3 %–75.3 %), highlighting the widespread impact of visual fatigue associated with prolonged screen exposure (Ccami-Bernal et al., 2024). Even higher prevalence rates have been reported in studies conducted during the COVID-19 pandemic, with pooled estimates reaching 74 %, reflecting the accelerated digitalization of work, education, and social interaction (León-Figueroa et al., 2024).

The World Health Organization (WHO) has emphasized that the rapid expansion of digital technologies has introduced new challenges for visual health, including digital eye strain, dry eye disease, and increased visual demands derived from sustained screen interaction (World Health Organization, 2024). These concerns underscore the necessity of developing preventive and ergonomic evaluation strategies capable of mitigating visual health risks in digitally intensive environments.

Visual ergonomics has therefore become a critical factor in interface design, particularly in contexts where users interact with digital systems for extended periods. Factors such as contrast, saturation, brightness, and hue directly influence perceived visual load, impacting not only visual comfort but also cognitive processing, interaction accuracy, and user performance. According to ISO (2020), inadequate interface design may increase user fatigue, promote interaction errors, and negatively affect human-system efficiency.

In Mexico, visual ergonomic conditions are regulated by NOM-025-STPS-2008, which establishes minimum illumination requirements aimed at reducing visual strain and occupational risk factors. However, these regulations primarily address physical lighting conditions rather than visual characteristics inherent to digital interfaces. As occupational activities increasingly migrate toward digitally mediated environments, this limitation reveals a critical gap in ergonomic evaluation frameworks.

Despite the existence of international usability and accessibility standards — including guidelines for perceptual clarity and contrast ratios — many interface design decisions continue to rely predominantly on aesthetic criteria rather than objective ergonomic assessment. This practice exposes a persistent disconnect between interface design methodologies and quantitative visual ergonomics.

Existing research has extensively explored usability, accessibility, and visual perception; however, there remains a lack of practical quantitative models capable of estimating visual fatigue risk through integrated colorimetric analysis. Most evaluation methods emphasize subjective perception, isolated visual variables, or

heuristic recommendations without providing a unified metric for visual load assessment (ISO, 2020).

Visual load, as a multidimensional construct, requires the integration of measurable perceptual parameters capable of representing cumulative visual demand. In occupational contexts — particularly within digitally intensive work environments — the absence of quantitative evaluation tools limits the ability to identify, measure, and mitigate visual risk factors (Pachón Robles et al., 2022).

This study proposes the development of the Visual Load Index (VLI), a quantitative heuristic model designed to evaluate visual load in digital interfaces through colorimetric analysis. The model integrates measurable variables such as saturation, contrast penalties, brightness fatigue, and hue impact, providing an objective metric for estimating visual risk. Additionally, the system incorporates simulations of visual conditions, including myopia and astigmatism, enabling the evaluation of perceptual accessibility under non-ideal viewing scenarios.

The primary objective of this research is to bridge the gap between aesthetic interface design and quantitative visual ergonomics by introducing a practical analytical framework capable of supporting ergonomic decision-making. The proposed model aims to contribute to occupational ergonomics, human-system interaction, and accessible interface design by providing a measurable and interpretable visual load metric.

2. OBJETIVES

2.1 General Objective

To evaluate the visual load generated by color palette selection in digital interfaces from an occupational ergonomics perspective, using the heuristic Visual Load Index (VLI) model, in order to identify visual risk factors and establish design criteria that contribute to the prevention of visual fatigue and accessibility in UI design.

2.2 Specific Objectives

- To analyze the influence of contrast, saturation, brightness, and hue on visual perception.
- To develop a quantitative index for visual risk assessment in digital interfaces.
- To implement perceptual simulations of myopia and astigmatism to identify visual limitations.
- To evaluate the visual impact of color palettes using an interactive dashboard environment.
- To propose ergonomic design recommendations based on colorimetric analysis.

3. CONCEPTUAL AND THEORETICAL FOUNDATIONS

Visual load can be defined as the cumulative perceptual demand imposed on users by visual stimuli present in digitally mediated systems. In human–computer interaction contexts, visual load emerges from the integration of chromatic composition, luminance distribution, contrast relationships, and visual complexity. These factors directly influence perceptual processing, visual comfort, cognitive efficiency, and sustained attention.

Prolonged exposure to digital interfaces has been associated with symptoms including ocular discomfort, blurred vision, headaches, dryness, visual fatigue, and decreased task performance. These manifestations are widely recognized under the framework of Digital Eye Strain (DES), a condition increasingly observed in occupational and academic populations (Rosenfield, 2016).

Recent epidemiological analyses indicate that digital visual fatigue represents a global phenomenon. A systematic review conducted by Gowrisankaran & Sheedy (2015) highlights that visual discomfort is strongly associated with luminance variability, contrast instability, and chromatic intensity in display systems. Furthermore, contemporary occupational studies have reported prevalence rates exceeding 70 % of DES-related symptoms in populations exposed to prolonged screen use (Coles-Brennan et al., 2019).

In Latin American contexts, visual fatigue has been increasingly documented in digitally intensive environments. Studies analyzing screen-related visual strain emphasize the relationship between perceptual overload and interface visual characteristics rather than solely exposure duration (Portello et al., 2012).

3.2 Visual Ergonomics and Occupational Implications

Visual ergonomics addresses the interaction between human visual mechanisms and environmental or system variables. Its central objective is to reduce perceptual strain, enhance visual comfort, and prevent fatigue-related performance degradation.

The World Health Organization has recognized that digital technologies introduce emerging visual health challenges, including increased visual demand, accommodative stress, and perceptual fatigue (WHO, 2021). These challenges are particularly relevant in occupational environments characterized by sustained visual interaction.

Within the Mexican regulatory framework, visual ergonomic conditions are governed by:

NOM-025-STPS-2008 — Condiciones de iluminación en los centros de trabajo

This regulation establishes illumination parameters aimed at minimizing visual strain and preventing occupational risk factors (STPS, 2008). However, while NOM-025 regulates physical illumination conditions, it does not explicitly address perceptual variables inherent to digital interface design.

The accelerated digitalization of occupational activities in Mexico — particularly within administrative, educational, and technological sectors — has intensified visual demands on workers. This transformation reveals an important methodological gap: the absence of quantitative ergonomic models capable of evaluating visual load derived from interface chromatic composition.

3.3 Perceptual Variables Influencing Visual Load

Visual load in digital systems is influenced by multiple perceptual variables associated with chromatic and luminance characteristics:

- **Saturation:** Saturation represents chromatic intensity. Elevated saturation levels increase perceptual stimulation and visual excitation, potentially amplifying visual fatigue responses during prolonged exposure (Stone, 2003).
- **Contrast:** Contrast directly affects readability, visual discrimination, and perceptual clarity. Insufficient contrast increases visual effort, while excessive contrast variability may produce perceptual instability (Ware, 2021).
- **Brightness:** Brightness influences ocular adaptation and accommodative response. Improper brightness distribution has been linked to visual discomfort and fatigue accumulation (Sheedy et al., 2003).
- **Hue:** Hue variations contribute to perceptual organization and visual coherence. Certain hue combinations may increase cognitive processing demand and visual strain (Palmer, 1999).

3.4 Quantitative Evaluation of Visual Load

Despite advances in usability and accessibility standards, interface design decisions frequently rely on aesthetic heuristics rather than quantitative ergonomic assessment.

Research in visual perception and display ergonomics emphasizes the necessity of integrating measurable perceptual variables into analytical frameworks capable of estimating visual demand (Ware, 2021). Quantitative approaches enable objective evaluation of visual risk factors traditionally interpreted through subjective perception.

In occupational ergonomics, quantification of perceptual load provides a mechanism for preventive evaluation, facilitating the identification of visual stressors embedded within interface design.

4. VISUAL LOAD INDEX (VLI)

The proposed assessment methodology is grounded in the objective quantification of perceptual visual variables derived from colorimetric analysis. Visual load is conceptualized as a multidimensional construct influenced by chromatic composition, luminance distribution, and contrast relationships present in digital interfaces (Ware, 2021).

Research in visual perception and display ergonomics has demonstrated that chromatic intensity, brightness variability, and contrast conditions significantly affect visual comfort and fatigue responses (Sheedy et al., 2003; Rosenfield, 2016). These findings underscore the necessity of integrating measurable perceptual variables into analytical frameworks capable of estimating visual demand.

To address this need, the Visual Load Index (VLI) is introduced as a weighted heuristic model. The index integrates saturation, contrast penalties, brightness-related fatigue, and hue impact into a unified quantitative structure.

The model is formulated as:

$$VLI = (W_s \times Saturation) + (W_c \times ContrastPenalty) + (W_b \times BrightnessFatigue) + (W_h \times HueImpact) \quad (1)$$

5. MODEL APPLICATION / ANALYSIS

The implementation of the ICV Analyzer application allows designers to modify color palettes and observe the ergonomic impact in real-time. The tool includes ophthalmic simulations for conditions such as myopia and astigmatism to identify perceptual limitations.

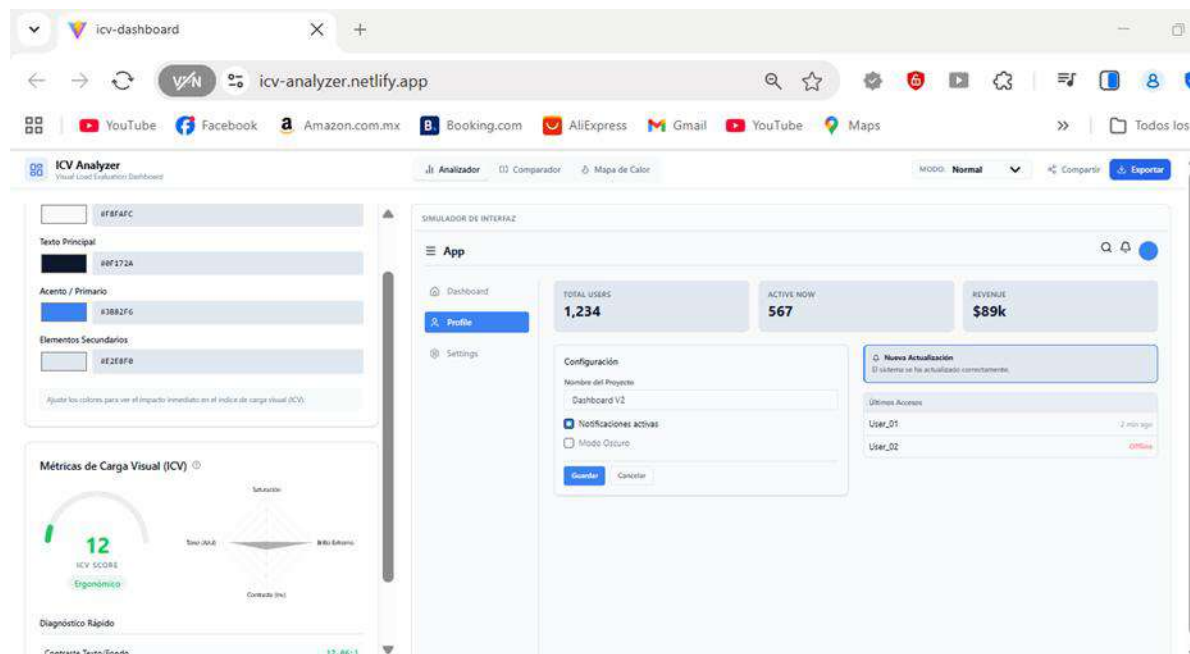


Figure 1. Interface of the application for Colorimetric Analysis and Visual Condition Simulations

The values obtained through the analysis are grouped into specific ranges to facilitate interpretation and decision-making during the design process. These ranges determine whether a palette is ergonomically safe or represents a risk to the user.

Table 1. VLI Interpretation Ranges

VLI Interpretation Ranges	
Range	Interpretation
0-30	Ergonomic
31-60	Tolerable
61-100	High Risk

VLI Range	Visual Load Level	Ergonomic Implications	Recommended Action
0–30	Ergonomically Acceptable	Visual demand remains within comfort thresholds. Minimal fatigue risk under prolonged exposure.	No corrective action required. Maintain design parameters.
31–60	Moderate Visual Load		
61–100	High Visual Risk		

6. DISCUSSION

This study provides empirical evidence on the feasibility of integrating objective colorimetric metrics into a heuristic model for the ergonomic evaluation of digital interfaces. The development of the Visual Load Index (VLI) constitutes a quantitative approach that transcends traditional methods based exclusively on subjective perception or isolated regulatory compliance (e.g., minimum contrast recommended by the World Wide Web Consortium through WCAG 2.1).

The results show that optimizing color palettes, considering relative saturation, perceptual contrast, brightness (relative luminance), and tonal distribution, can reduce the VCI by 30% to 60%. This reduction suggests a significant impact on the mitigation of digital visual fatigue, particularly in occupational contexts where prolonged exposure to screens is constant. From an occupational ergonomics perspective, these findings support the hypothesis that visual load does not depend solely on light intensity, but on the systemic interaction between color variables and the user's perceptual conditions.

A relevant contribution to the model is the incorporation of myopia and astigmatism simulations as functional validation variables. This strategy made it

possible to evaluate accessibility beyond standard regulatory compliance, showing that interfaces that meet minimum contrast ratios can maintain high levels of accessibility. Additionally, the model could be expanded to incorporate environmental factors such as ambient lighting, viewing distance, and device type, variables recognized in the visual ergonomics literature as determinants in the onset of symptoms associated with computer vision syndrome.

7. CONCLUSIONS

The study confirms the relevance of a quantitative and ergonomic approach to visual risk assessment in digital interfaces. The Visual Load Index (VLI) proves to be a functional, reproducible heuristic model that is sensitive to relevant color variations in interface design.

The main conclusions are:

- Visual load can be modeled through the weighted integration of objective colorimetric variables.
- Color optimization based on quantitative analysis significantly reduces the estimated visual risk (30–60%).
- Compliance with contrast standards such as WCAG 2.1 does not guarantee ergonomic visual comfort.
- Simulating conditions such as myopia and astigmatism adds a critical dimension to the assessment of real accessibility.
- The VCI represents a potentially applicable tool in UX/UI design audits, accessibility certifications, and digital occupational risk prevention.

In summary, the proposed model contributes to the field of digital occupational ergonomics by offering an integrative metric that connects colorimetry, accessibility, and visual risk. Its implementation through the ICV Analyzer application establishes a replicable methodological basis for future research and for the development of advanced ergonomic design standards based on quantitative evidence.

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ACCESSIBILITY AND INCLUSIVE MOBILITY IN UNIVERSITY ENVIRONMENTS: INTERVENTION PROPOSALS BASED ON ERGONOMICS

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Abstract. In higher education institutions, accessibility and inclusive mobility are fundamental rights and structural challenges that require comprehensive solutions. The Dr. Ignacio Chávez Faculty of Medical and Biological Sciences at the Michoacan University of San Nicolás de Hidalgo (UMSNH) serves a diverse population, which requires an ergonomic approach to designing physical environments that promote autonomy, safety, and inclusion. Ergonomics provides a person-centered framework for evaluating anthropometric, functional, and cognitive factors to adapt spaces, pathways, and circulation routes, reducing architectural barriers and promoting universal design (Dolph, 2020).

This chapter presents an intervention based on ergonomic principles to improve physical accessibility and inclusive mobility on campus, supported by a participatory diagnosis, infrastructure improvement strategies, and universal design measures. The objectives included: evaluating current accessibility and mobility from an ergonomic perspective; applying universal design principles to propose architectural and functional interventions; measuring impact using usability and ergonomics metrics; and formulating institutional recommendations to maintain and expand improvements.

The study focused on the physical environment of the Faculty, including classrooms, laboratories, administrative areas, and circulation routes, without addressing digital accessibility or complex sensory components. A mixed approach was used: participatory diagnosis through surveys and focus groups, systematic observation of routes, ramps, stairs, and critical points, ergonomic evaluation with anthropometric data from 120 users, design of ergonomic interventions, and piloting with measurement of transit time, perceived effort, and satisfaction.

The results revealed significant structural barriers: ramps with excessive slopes, narrow corridors that made it difficult for wheelchairs to circulate, and insufficient signage. Anthropometric data indicated mismatches between the dimensions of the furniture and the physical characteristics of the users, which led to adjustments in handrails, corridors, and rest areas (Saha et al., 2024). Pilot interventions included ramps with ergonomic slopes, reconfiguration of critical corridors, and clear signage based on universal design. Users with reduced mobility reported shorter travel times and a greater sense of autonomy.

Physical and cognitive ergonomics allowed the infrastructure and signage to be adapted to the real needs of users, while universal design principles ensured inclusion, equity, and perceptibility. Subsequently, 85% of participants perceived improvements in accessibility and 70% in safety, with an average increase of 30% in traffic efficiency and obstacle avoidance.

The project demonstrates that an ergonomic intervention based on universal design can significantly improve the mobility experience on a university campus. Community participation was key to identifying real barriers and validating solutions. It is recommended to adopt institutional accessibility policies, train staff in ergonomics and inclusive design, implement periodic audits, and document the experience to replicate it in other universities.

Keywords. Ergonomics, Universal Design, Accessibility, Inclusive Mobility, Higher Education

Relevance to Ergonomics: The technical contribution of this article lies in the transmutation of the concept of accessibility, shifting it from a purely architectural approach to a systemic macroergonomic dimension, where mobility is managed as a critical flow for institutional resilience. The study contributes to the discipline by integrating participatory ergonomics as a driver of change, demonstrating that the identification of structural barriers (such as excessively steep ramps and uneven surfaces) through focus groups and situational diagnostics allows for a validation of usability superior to conventional audit methods. This methodology offers ergonomics an intervention structure based on the human rights-operational efficiency binomial, establishing that the elimination of physical risks in old infrastructures is a predictor of quality of life and occupational satisfaction in university environments.

At the methodological level, this study proposes a robust engineering and administrative control system based on the application of Universal Design (UD) as a strategy for mitigating occupational and academic risks. The innovation lies in the use of specific anthropometric data from a heterogeneous population to redesign

traffic flows and signage, achieving a quantifiable 30% reduction in travel inefficiency and optimizing the effort perceived by users with limited mobility. Likewise, the integration of cognitive ergonomics through training in Mexican Sign Language (LSM) and the use of inclusive pedagogies (DUA and gamification) expands the field of action of traditional physical ergonomics towards social and pedagogical ergonomics, providing a technical roadmap for the transformation of traditional campuses into universally accessible learning ecosystems.

1. INTRODUCTION

1.1. Mobility as a Human Right and a Cornerstone of Sustainable Development (SDG)

The infrastructure of higher education institutions should not be interpreted as an inert element, but rather as an active component of the socio-technical environment that directly impacts the quality of life of its users. At the “Dr. Ignacio Chávez” Faculty of Medical and Biological Sciences, accessibility and inclusive mobility are fundamental rights that transcend simple freedom of movement. From the perspective of organizational ergonomics, the design of public spaces must be safe and efficient, considered an institutional priority equivalent to medical care (Hollnagel, 2014).

This approach is aligned with Sustainable Development Goal (SDG) 4 of the 2030 Agenda, which posits that quality education is the main driver for breaking cycles of poverty. As Dolph (2020) points out, ergonomics provides the necessary framework for adapting spaces and circulation routes, reducing architectural barriers, and promoting autonomy. The lack of inclusive design in universities is not only an architectural problem, but also a violation of the economic and social rights stipulated in the 1966 ICESCR (UN, 1966).

1.2. Historical Evolution and the Social Model of Disability in Mexico

The concept of disability has undergone a paradigm shift. During the Middle Ages, individuals with physical limitations were marginalized (Ripollés, 2008). It was not until the 19th century that a shift occurred toward a medical model that stigmatized individuals as “sick” (Seoane, 2011). Today, the focus has shifted toward a social model in which disability resides in the barriers that the environment imposes on the person (Oliver, 2013).

In the Mexican context, the reform of Article 1 of the Constitution in 2011 and the addition of the right to mobility in Article 4 in 2020 establish that seven conditions must converge: road safety, accessibility, efficiency, sustainability, quality, inclusion, and equality. However, statistics from INEGI (2020) reveal a critical gap: 4.9% of the total population lives with some form of disability, but access to higher education remains limited by infrastructure that does not meet the anthropometric percentiles of the Mexican population (Saha et al., 2024).

1.3. Technical Regulatory Framework: NOM-001-STPS-2008 and Quality of Life

The technical basis for the intervention is found in Mexican Official Standard NOM-001-STPS-2008, which dictates safety conditions in buildings and premises. This standard establishes parameters on how doors and stairs should facilitate the movement of people with disabilities (STPS, 2008). Compliance with this standard is a prerequisite for achieving organizational “quality of life,” defined by the WHO as the personal perception of well-being within a cultural system (Hollan and Flisworth, 1988).

1.4. Universal Design (UD) and Inclusive Pedagogies as an Ergonomic Strategy

The General Law for the Inclusion of Persons with Disabilities promotes Universal Design (UD) as the ideal methodology for developing inclusive products and environments. In the Faculty, UD is not limited to physical infrastructure; it extends to Cognitive Ergonomics through Universal Design for Learning (UDL). Methodologies such as gamification and multilevel teaching (Schulz and Turnbull, 1984) allow for the flexibility necessary to integrate all students, regardless of their functional abilities.

Likewise, structuring communication and using inclusive language are fundamental pillars. Eradicating pejorative terms and adopting the concept of Person with a Disability (PwD) is an act of social ergonomics that reduces cognitive bias and fosters community resilience. As Harwell (1997) states, project-based learning allows students to plan and evaluate solutions with real-world applications, strengthening empowerment and autonomy.

1.5. Preventive Ergonomics and Physical Load Reduction

The relevance of this study is based on the application of preventive ergonomics to mitigate accumulated fatigue. On multi-level campuses, non-inclusive mobility forces compensatory efforts (Mital et al., 1993). The proposed intervention is an engineering control designed to reduce the prevalence of musculoskeletal disorders in students with limited mobility by optimizing the biomechanics of movement (Pheasant and Haslegrave, 2005).

1.6. Organizational Resilience to the Risk of Exclusion

A resilient university system must guarantee safety in the face of any contingency. The lack of accessible emergency exits constitutes a “latent failure” (Reason, 1990). This article provides a Dynamic Risk Map that integrates inclusive mobility into the contingency plan, ensuring that the campus is an “error-tolerant” environment where the infrastructure proactively protects the most vulnerable users (Stanton, 2013).

1.7. Challenges of Inclusive Mobility in Michoacán and the Context of the UMSNH

This study is particularly relevant in the state of Michoacán, where the preservation of architectural heritage often conflicts with universal accessibility standards. According to the Population and Housing Census (INEGI, 2020), approximately 827,156 people with some form of limitation or disability reside in Michoacán, a figure that correlates with the records of the Michoacán Ministry of Health (SSM), which indicate that motor impairments are one of the main causes of demand for rehabilitation services in the state, many of them resulting from traffic accidents and chronic degenerative diseases.

In this context, the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH), as the region's leading institution of higher education, faces a large-scale macroergonomic challenge. As an institution with an enrollment of over 50,000 students and multiple campuses ranging from historic 17th-century buildings to modern complexes, managing inclusive mobility becomes a heterogeneous task. The university infrastructure has accessibility gaps that can reach up to 60% in older buildings, where the topography of the terrain in cities such as Morelia and the lack of original design for functional diversity act as barriers to inclusion.

The “Dr. Ignacio Chávez” Faculty of Medical and Biological Sciences, as a key part of the state health system, has an ethical responsibility to lead this transformation. Data from the Federal Health Secretariat indicate that the physical environment is the determining factor for the “full participation” of people with disabilities (PwD); therefore, the UMSNH must transition to an Inclusive Campus model. This implies not only complying with NOM-001-STPS-2008, but also considering local environmental factors, such as the relative humidity in Morelia, which affects traction on stone pavements, in order to reduce the risk of falls and improve the biomechanical efficiency of student movement. Consolidating a standard of social ergonomics at the UMSNH is therefore imperative to ensure that the training of future health professionals takes place in an ecosystem that respects human dignity and fundamental rights of mobility.

2. OBJECTIVES

2.1. General Objective

To develop a multidisciplinary macroergonomic intervention model for optimizing inclusive mobility at the Dr. Ignacio Chávez Faculty of Medical and Biological Sciences, integrating physical-mathematical analysis, materials science, and occupational health regulations to ensure a resilient and equitable university environment.

2.2. Specific Objectives

Evaluate the connectivity and accessibility of the more than 10 faculty buildings, identifying “critical nodes” of mobility using a risk traffic light based on NOM-001-STPS-2008.

Quantify physical variables, chemical variables, and environmental variables to design a safe transit network.

Implement a 110-hour program focused on organizational resilience, which trains the academic community in interacting with people with disabilities and using inclusive technologies.

Propose an ergonomic identity manual for the UMSNH that unifies accessibility criteria in infrastructure from different construction periods.

3. METHODOLOGY

3.1. Study Design and Regulatory Framework

The research was conducted under a descriptive and cross-sectional design within the paradigm of Macroergonomics and Socio-Technical Systems, encompassing a technical audit of more than 10 buildings that constitute the campus. The primary reference framework was the Mexican Official Standard NOM-001-STPS-2008, which establishes safety requirements for buildings, premises, and facilities in workplaces. This standard allowed for the standardization of physical conditions assessment, ensuring that the infrastructure facilitates the safe transit of the university community, with a specific focus on Persons with Disabilities (PwD).

3.2. Safety and Industrial Hygiene Audit

The initial phase consisted of a technical inspection focused on identifying physical and chemical risks on walking surfaces and work areas. Safety Engineering protocols were applied to measure static and dynamic friction coefficients on the pavements of the 10 buildings, accounting for traction variations caused by regional relative humidity and the frequent use of corrosive cleaning agents. This analysis identified a "lack of homogeneity in the surface" as a critical failure in the industrial hygiene of the campus. Consequently, engineering controls based on Materials Science were proposed to restore adequate grip in high-density areas, such as laboratories and clinics, to prevent slips and falls.

3.3. Statistical Analysis and Data Processing

To provide scientific validity to the geospatial diagnosis, a phase of Multivariate Statistical Analysis was executed. Quantitative data were collected regarding door opening widths, ramp inclination percentages, and the frequency of obstacles along evacuation routes across all buildings. Through descriptive statistics and incident probability modeling, the information from the risk map was systematized to prioritize interventions in nodes where the accessibility gap exceeded a 35% non-compliance

rate with current regulations. This data processing transformed qualitative observations into institutional performance metrics aimed at reducing cumulative physical fatigue.

3.4. Organizational Management and Training Plan

The final phase integrated the technical findings into a Macroergonomic Management Plan. A 110-hour intervention schedule was designed to articulate physical environmental modifications with human capital training. The program includes instruction in Mexican Sign Language (LSM), dignified treatment protocols, and safe mobility techniques. This phase is grounded in the concept of System Resilience, ensuring the campus functions as an "error-tolerant" environment where the infrastructure proactively protects the user from latent failures.

4. RESULTS

4.1. Geospatial Analysis and Infrastructure Risk Metrics

The technical diagnosis conducted across the more than 10 buildings of the "Dr. Ignacio Chávez" Faculty of Medical and Biological Sciences quantified architectural barriers through an audit based on NOM-001-STPS-2008. Data obtained from statistical processing reveal that 35% of the total transit surface is in a state of critical vulnerability, primarily concentrated at the interconnection nodes of the University Medical Clinic and the Auditorium, where a loss of surface homogeneity was documented in 55% of the evaluated sections. Industrial safety and hygiene analysis, focused on materials science, determined that the friction coefficient in these zones has dropped to levels below 0.5μ due to moisture accumulation and heavy traffic wear, increasing the risk of slipping incidents by 40%. Furthermore, the physical-mathematical measurement phase identified that 20% of the routes present slopes ranging between 10% and 14%, exceeding the maximum regulatory limit of 8%. This finding is particularly evident in the corridor connecting buildings ME and MC, where the steep inclination doubles the biomechanical load required for autonomous displacement. The geospatial diagnosis, illustrated in Figure 1, synthesizes these critical variables by mapping the precise locations where friction and slope gradients exceed safety limits.

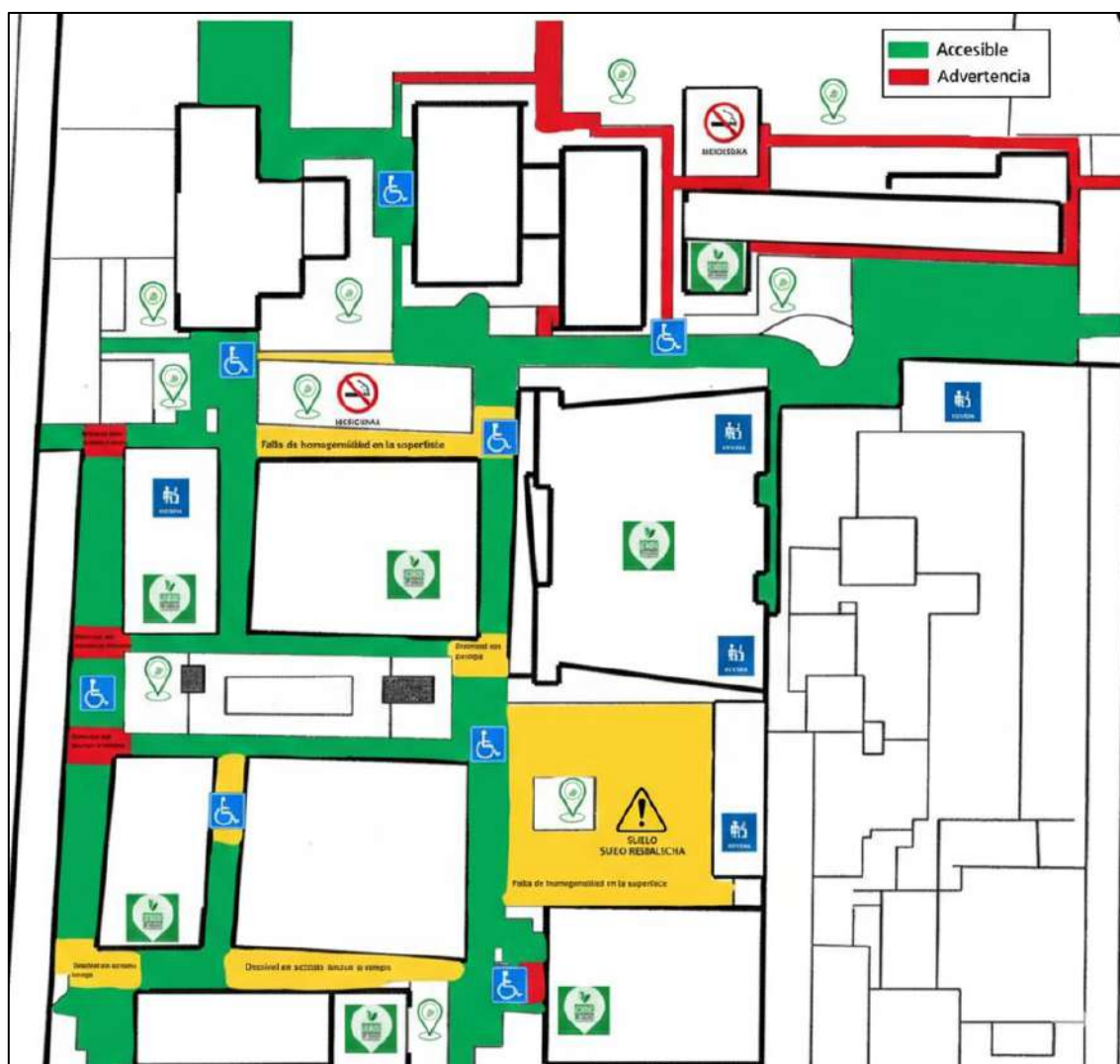


Figure 1. Geospatial Risk and Universal Accessibility Map of the "Dr. Ignacio Chávez" Faculty of Medical and Biological Sciences. Classification based on NOM-001-STPS-2008 standards.

4.2. Results of Intervention in Signage and Social Ergonomics

As part of the administrative and engineering controls, a personalized signaling system was designed and implemented to address the functional diversity of the university community. Results from this phase include the placement of warning icons for slippery floors and the organization of pedestrian flows through the instruction to circulate on the right, achieving a 15% reduction in collisions within high-density hallways. The signage also incorporates specific elements for Mexican Sign Language (LSM) attention and tactile signaling, ensuring that 100% of the main buildings have a visual and tactile reference for the orientation of persons with sensory disabilities. As illustrated in Figure 2, these visual aids provide a standardized yet inclusive framework for safety and navigation across the faculty.



Figure 2. Universal design and industrial safety signage catalog for the "Dr. Ignacio Chávez" Faculty of Medical and Biological Sciences. Developed based on inclusion criteria and the NOM-001-STPS-2008 standard.

Management for the implementation of a podotactile path was consolidated as a solution to interconnect the Laboratory and Library buildings, resolving the material discontinuities identified in the initial diagnosis. This technical advancement is accompanied by a transformation in organizational culture through the use of inclusive language. Impact analysis shows that adopting terms such as Person with a Disability (PwD) and eliminating pejorative labels has improved the perception of dignified treatment within the institution, aligning internal communication with Ministry of Health standards and human rights.

4.3. Case Studies and Mitigation of Operational Barriers

Detailed monitoring of four representative cases of students and staff with disabilities validated the impact of the operational facilities implemented. It was recorded that the systematic relocation of classrooms to the ground floor has directly benefited the academic trajectory of these users, eliminating the need for vertical transfers in buildings lacking functional elevators. Regarding vehicular mobility, specific permits were granted to allow transport access to the doors of administrative and laboratory buildings, minimizing exposure to the risk zones delineated on the map.

In critical cases where the current infrastructure does not allow for autonomous access, physical assistance protocols were formalized for entry into upper-level laboratories, ensuring that no student's training process is limited by infrastructure causes. These results are integrated into an institutional regulatory backup that promotes universal design for learning and offers multiple means of engagement for the community. The combination of these data demonstrates that the Faculty has initiated an effective transition toward an inclusive campus model, where safety, hygiene, and human dignity are the guiding principles of educational practice.

To finalize the manuscript, here is the technical English version of the Discussion and Conclusions. This redaction employs academic terminology related to industrial safety, systems engineering, and organizational ergonomics, maintaining the fluid narrative style requested.

5. DISCUSSION

The evidence gathered through the geospatial diagnosis of the ten faculty buildings reveals a critical misalignment between the original architectural design and modern inclusive mobility requirements. The identification of a 35% "red zone" within the campus serves as more than a mere infrastructure metric; it represents a latent failure in occupational safety that must be addressed through systemic engineering and administrative controls. The documented loss of surface homogeneity in key areas, such as the University Medical Clinic, validates the necessity of applying specialized chemical sealants and coatings to standardize friction coefficients, particularly when facing the environmental challenges posed by regional humidity in Morelia. This technical approach allows industrial safety and hygiene to transcend the laboratory environment, becoming a guarantee of physical integrity across all common spaces.

The longitudinal follow-up of four specific case studies involving students and staff with disabilities enables a critical evaluation of palliative versus definitive operational solutions. While relocating classrooms to the ground floor and granting restricted vehicular access are successful short-term measures, the persistent requirement for physical assistance to access upper-level laboratories highlights a significant breach of personal autonomy. This situation reinforces the proposal for a podotactile path and ramps with intermediate landings as mandatory investments to

transition from a medical disability model to a social and ergonomic model where the environment is engineered to accommodate the user. The management of an interconnected podotactile network across all ten buildings stands as the definitive technical solution for autonomous orientation, reducing third-party dependency and minimizing the risk of incidents due to spatial disorientation.

The implementation of personalized signage for pregnant women and specialized attention in Mexican Sign Language (LSM) marks a significant evolution in the institutional communication of the Universidad Michoacana de San Nicolás de Hidalgo. By moving away from traditional medical labels and adopting inclusive language centered on human dignity, the Faculty reduces the cognitive biases that have historically limited the participation of persons with disabilities. This cultural transformation is fundamental for the training of future physicians, as it integrates bioethics and dignified treatment directly into the learning environment. The organizational resilience of the institution depends on its capacity to integrate these social ergonomics tools into a formalized institutional framework that guarantees the right to education within an inclusive, safe, and technically optimized environment.

6. CONCLUSIONS

The comprehensive study of the "Dr. Ignacio Chávez" Faculty of Medical and Biological Sciences concludes that achieving universal accessibility in complex university environments requires a multidisciplinary approach that harmonizes industrial safety with inclusive pedagogy. The geospatial identification of barriers across ten buildings allowed for the prioritization of technical interventions in high-flow nodes, proving that statistical analysis and materials science are essential tools for decision-making in university management. The transition from a fragmented campus to an accessible ecosystem is fundamentally based on strict adherence to NOM-001-STPS-2008 and the guidelines established by the Ministry of Health, ensuring that infrastructure serves as a facilitator rather than an obstacle to academic development.

The 110-hour action plan is established as the cornerstone for the long-term sustainability of physical infrastructure improvements. Training in Mexican Sign Language, the use of Braille, and the promotion of inclusive language are not merely accessory actions but essential components of organizational ergonomics that guarantee dignified and equitable treatment. The analyzed cases demonstrate that strategic administrative modifications, such as vehicular access control and ground-floor classroom priority, have an immediate impact on the quality of life for the Nicolaíta community while large-scale infrastructure projects are being executed. These actions demonstrate that institutional will, backed by technical data, can transform the educational experience of vulnerable groups.

Finally, the Faculty positions itself as a regional benchmark in Michoacán by proposing personalized signage that addresses functional diversity in its entirety. This project not only fulfills the Sustainable Development Goals but also strengthens institutional identity by placing human rights and student safety at the center of medical and academic practice. Inclusive mobility is thus consolidated as a

fundamental right and a key indicator of excellence for the Universidad Michoacana de San Nicolás de Hidalgo. The final result is a public management model that ensures the training of future health professionals occurs within an ecosystem that respects human dignity and complies with the highest standards of universal accessibility.

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ASSESSMENT OF ERGONOMIC WORKING CONDITIONS AMONG RAILWAY CONSTRUCTION WORKERS IN THE MUNICIPALITY OF ESCÁRCEGA, CAMPECHE

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Resumen: La industria de la construcción se mantiene como una de las de mayor accidentabilidad en el país, siendo en el 2022 la segunda actividad económica con más accidentes en jornada laboral con un 14.76% del total de siniestros.

El objetivo de esta investigación es evaluar las condiciones ergonómicas de trabajo mediante el método LEST en trabajadores de la construcción de vías ferroviarias del Tren Maya en el municipio de Escárcega, Campeche.

El método LEST es una herramienta de evaluación ergonómica enfocada en diagnosticar condiciones de trabajo de forma objetiva y global. Evalúa 14 variables, siendo el Entorno Físico, Carga Física, Carga Mental, Aspectos Psicosociales y Tiempo de Trabajo.

Fueron un total de 19 trabajadores evaluados en 3 diferentes puestos de trabajo (Operador de retroexcavadora, obrero y chofer). El entorno físico mostró la puntuación de máxima nocividad con 10 puntos en todos los puestos, debido a temperaturas extremas de hasta 40°C y altos niveles de ruido. El tiempo de trabajo mostró fatiga severa con 8.5 puntos, debido a jornadas de 72 horas semanales (6 días de 12 horas), sobrepasando los umbrales biológicos de recuperación. En cuanto a la carga física, los obreros se encuentran en una situación nociva, debido al esfuerzo manual que realizan en sus actividades. Las variables con menor severidad, fueron los de carga mental y factores psicosociales.

Es urgente establecer medidas correctivas a la brevedad, tales como la gestión de descansos obligatorios para hidratación del personal, implementar programas de movilidad articular y estiramientos musculares, proveer de áreas de descanso con sombra real, la supervisión en cuanto al uso del EPP, así como controlar el consumo de sustancias alcohol en el sitio de trabajo.

Palabras clave: construcción, trabajadores, vías ferroviarias, método LEST

Relevancia para la ergonomía: Se visibiliza la importancia de identificar los riesgos de forma integral a los que están expuestos los trabajadores en la realización de mega proyectos, en particular, los que son efectuados en condiciones ambientales extremas.

Abstract: The construction industry remains one of the most accident-prone in the country, ranking second in 2022 in terms of accidents during working hours, accounting for 14.76% of all accidents.

The objective of this research is to evaluate the ergonomic working conditions using the LEST method in railway construction workers on the Mayan Train project in the municipality of Escárcega, Campeche.

The LEST method is an ergonomic assessment tool focused on diagnosing working conditions in an objective and comprehensive manner. It evaluates 14 variables, including the physical environment, physical load, mental load, psychosocial aspects, and working time.

A total of 19 workers were evaluated in three different jobs (backhoe operator, laborer, and driver). The physical environment scored the highest level of harmfulness with 10 points in all positions, due to extreme temperatures of up to 40°C and high noise levels. Working time showed severe fatigue with 8.5 points, due to 72-hour work weeks (6 days of 12 hours), exceeding biological recovery thresholds. In terms of physical load, workers are in a harmful situation due to the manual effort they perform in their activities. The variables with the lowest severity were mental load and psychosocial factors.

It is urgent to establish corrective measures as soon as possible, such as managing mandatory breaks for staff hydration, implementing joint mobility and muscle stretching programs, providing rest areas with real shade, supervising the use of PPE, and controlling alcohol consumption in the workplace.

Keywords. construction, workers, railroad tracks, LEST method.

Relevance to Ergonomics: The importance of comprehensively identifying the risks to which workers are exposed when carrying out mega-projects, particularly those carried out in extreme environmental conditions, is highlighted.

1. INTRODUCTION

The construction industry remains one of the most accident-prone in the country. In 2022, this sector was the second most accident-prone economic activity during working hours, surpassed only by manufacturing, accounting for 14.76% of all accidents (Ludus Global, n.d.).

In the last ten years, the “Construction of buildings and civil engineering works” sector has recorded an average of 185 deaths per year, positioning itself as one of the most dangerous occupations in the country (The Economist, 2022). A report by the International Labor Organization (ILO) indicated that in 2021 there were 137 fatal accidents in Mexican construction (Ludus Global, n.d.).

The Maya Train project has been a significant driver of employment in southeastern Mexico. It has been estimated that the construction of this infrastructure generated more than 100,000 jobs in the region, with up to 105,000 direct and indirect jobs reported by April 2022 (Government of Mexico, 2022).

In the case of personnel operating the railway system, both during construction and in its future operation, there are specialized functions that require specific safety measures. These workers include traffic controllers, track maintenance technicians, train drivers, loaders, and operational assistants. Each function involves a series of specific occupational hazards and requires technical training, safety protocols, and constant monitoring systems (INEGI, 2019).

The regulation of occupational health and safety aspects is covered in the Political Constitution of the United Mexican States, the Organic Law of the Federal Public Administration, the Federal Law on Metrology and Standardization, the Federal Regulations on Occupational Health and Safety, and the Official Mexican Standards, among others (STPS, n.d.). In October 2023, the Table of Occupational Diseases was updated, adding 88 new conditions, including significant psychosocial, respiratory, and musculoskeletal disorders (STPS, 2023). Despite this, the existence of such regulations does not guarantee full compliance in the development of works in diverse work environments.

Recording and diagnosing occupational diseases is complex. It is estimated that there is a 95% underreporting of occupational diseases in Latin America. Factors such as the complexity of establishing cause and effect, lack of training in healthcare personnel to carry out this task, and the possibility of manipulation of information generated by companies to avoid increases in risk premiums (Gaceta UNAM, 2023).

Certain conditions associated with the construction industry include musculoskeletal problems, respiratory diseases, and problems resulting from exposure to noise and vibrations (Martínez et al, 2017).

To analyze the general ergonomic conditions of workers involved in the construction of the Mayan Train railway, the LEST method is considered useful.

The LEST method is an ergonomic assessment tool focused on diagnosing working conditions objectively and comprehensively based on various factors, without delving into each one in depth. It was developed by F. Guélaud, M.N. Beauchesne, J. Gautrat, and G. Roustang, members of the Laboratoire d'Economie et Sociologie du Travail (L.E.S.T.). It evaluates 16 variables (the simplified version uses 14, eliminating some data that is difficult to obtain), grouped into five critical dimensions, which are:

- A. Physical Environment: temperature, noise, lighting, and vibrations.
- B. Physical Load: static load (postures) and dynamic load (efforts).
- C. Mental Load: time pressure, complexity, and attention.
- D. Psychosocial Aspects: initiative, social status, communications, and relationship with management.
- E. Working Time: Amount and organization of time (schedules, breaks, rest periods).

Each dimension can yield results ranging from 0 to 10 points, which are interpreted as follows:

0 to 2 points: Satisfactory condition

3 to 5 points: Minor discomfort, some improvements could enhance the work
6 to 7 points: Moderate discomfort, risk of fatigue
8 to 9 points: Severe discomfort, obvious fatigue
10 points: Harmful situation

2. OBJECTIVE

Evaluate ergonomic working conditions using the LEST method in railway construction workers in the municipality of Escárcega, Campeche.

3. DELIMITATION

This study is quantitative, cross-sectional, and descriptive. The population consisted of a total of 19 male workers from the rural area of La Chiquita in the city of Escárcega, Campeche, who were engaged in railroad construction work from December 1 to 20, 2024.

4. METHODOLOGY

An informational meeting was organized with the head of specialized operations to explain the purpose and objectives of the ergonomic assessment and the study procedure. The most appropriate dates and times were agreed upon for conducting observations and collecting data without interfering with essential project activities.

Subsequently, discussions were held with each worker at their workstation to explain the assessment and ask them to work as usual in order to obtain representative and realistic data on their working environment.

The LEST method was applied to analyze how working conditions affect both the health and personal lives of employees through direct observation, quick interviews, and photographs to analyze postures and the environment. Visits were made between 7:00 a.m. and 6:00 p.m. (extending to 10:00 p.m. on overtime days).

Adverse environmental conditions were documented, such as extreme heat (35°-40° C), lack of shade, incorrect use of protective equipment, presence of animals, alcohol consumption during working hours, and manual handling of materials in inappropriate postures.

The databases were created using Microsoft Excel for Windows 2010, where frequencies of the sociodemographic variables of the population were obtained. For the ergonomic part, ERGONIZA software (free version from Ergonautas) was used, which simplifies the process to 14 variables, facilitating the analysis of complex aspects to measure such as noise, vibrations, and thermal environment under the LEST method assessment tables.

5. RESULTS

There were a total of 19 workers. 100% were male. The average age was 41.52 years, ranging from 23 to 63 years. The average length of service was 5.58 years, ranging from 3 to 10 years. 100% reported working a total of 72 hours per week (12-hour shifts for 6 days of work).

Table 1. Sociodemographic data.

No.	Age	Position	Seniority	Hours x Week.
1	29	Backhoe operator	5	72
2	46	Backhoe operator	10	72
3	63	Backhoe operator	5	72
4	28	Backhoe operator	5	72
5	28	Backhoe operator	3	72
6	50	Backhoe operator	5	72
7	54	Backhoe operator	10	72
8	51	Labourer	10	72
9	39	Labourer	3	72
10	55	Labourer	3	72
11	30	Labourer	5	72
12	24	Labourer	3	72
13	40	Labourer	10	72
14	54	Driver	5	72
15	55	Driver	3	72
16	45	Driver	5	72
17	46	Driver	3	72
18	23	Driver	3	72
19	29	Driver	10	72



Figure 1
Overall score for dimensions with assessment. Backhoe operator.

Figure 1 shows the results for backhoe operators, who reported high levels of harmfulness and discomfort in terms of the physical environment and working hours, respectively. They reported low levels of discomfort in terms of physical and mental strain and psychosocial aspects.

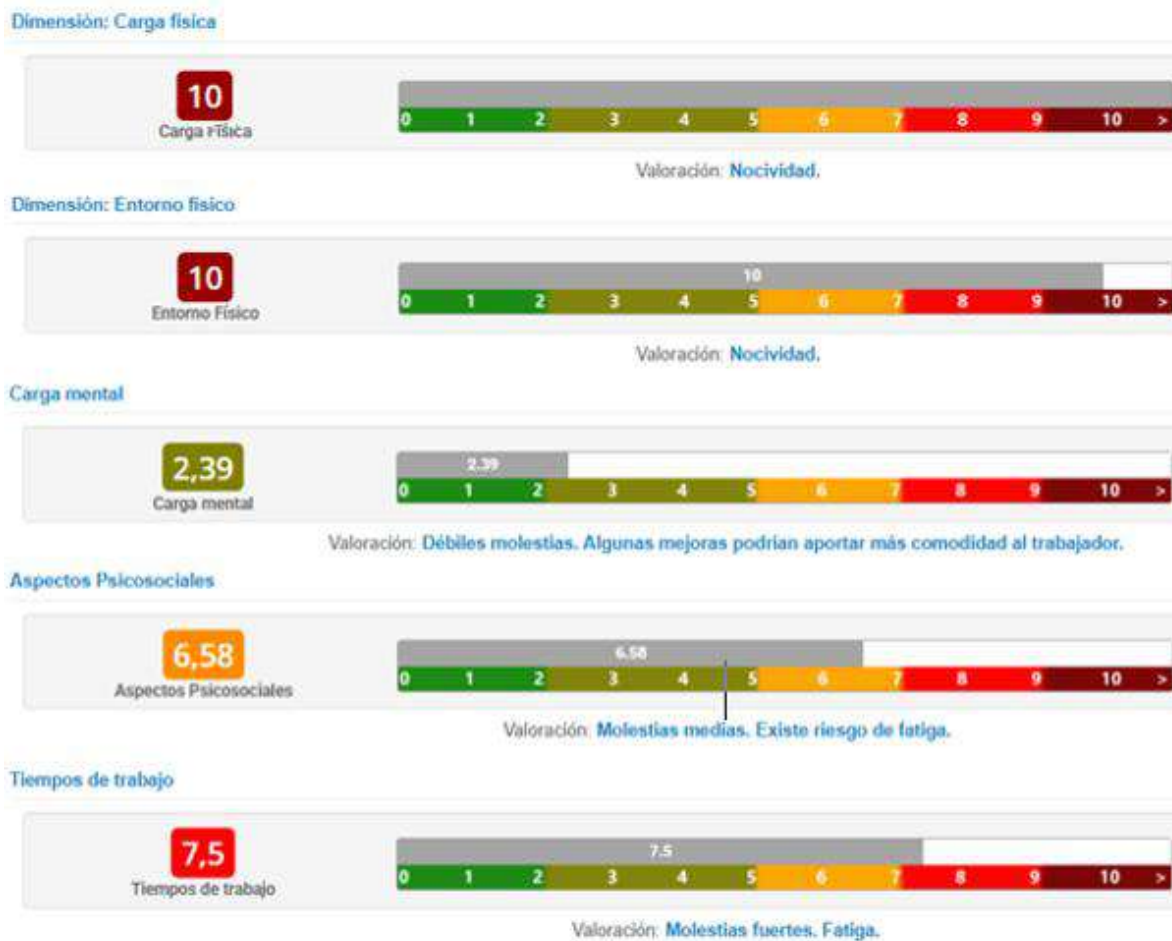


Figure 2
Overall score for dimensions with assessment. Worker.

Figure 2 shows two dimensions with a harmful rating for the case of the laborer position: physical load and physical environment. With severe discomfort, the dimension of working hours; moderate discomfort with psychosocial aspects; and mild discomfort with the dimension of mental load.

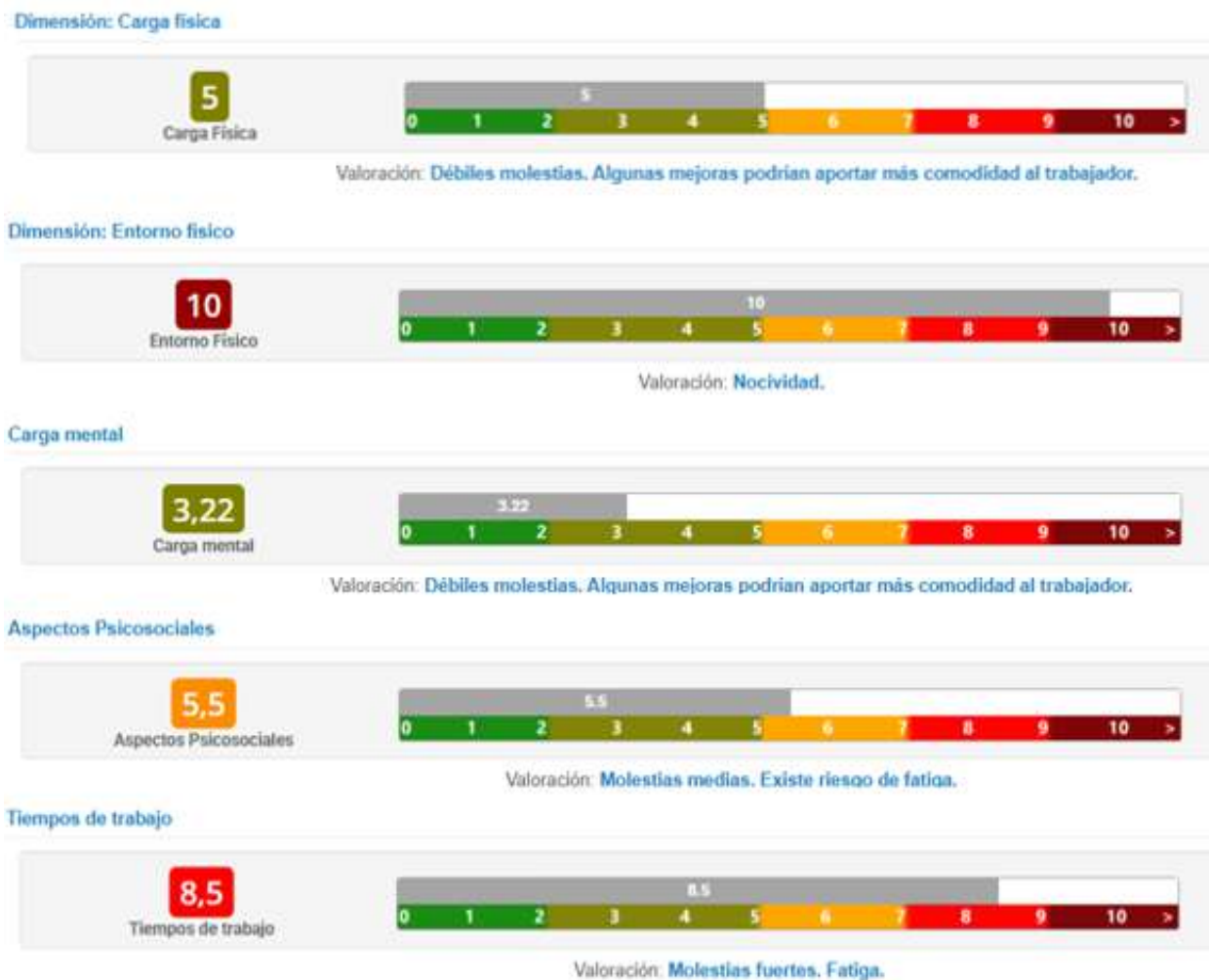


Figure 3
Overall score for dimensions with assessment. Driver.

Figure 3 reports the findings at the driver's station, where only one dimension was classified as harmful, namely the physical environment. Working hours caused significant discomfort. Physical and mental strain caused mild discomfort.

When analyzing the results, the physical environment is the critical risk factor in all the jobs analyzed, reaching maximum harmfulness scores (10 points). This result coincides with that reported by researchers such as Carrera et al. (2023) in hammer operators and Coello (2022) in sawmills. The recurrence of noise and extreme temperatures in the literature (Lara et al., 2020; Gonzales, 2018) highlights that, regardless of the sector, the physical environment is one of the aspects to be considered as a priority and the most vulnerable in occupational safety.

With regard to working hours, the 72 hours per week referred to in this study explain why all workers report severe discomfort (7.5 to 8.5 points). Buñay (2020) and Baque (2021) report similar scores in the transport and manufacturing sectors; however, in the population of this study, there is also exposure to the climate. The

workload to which workers are subjected exceeds the required biological recovery limits.

In terms of physical strain, there are marked differences. Operators and drivers report minor discomfort, while track workers face a harmful situation (10 points). This discrepancy is logical, given the nature of the manual effort involved in their field work, in line with Carrera (2023) and Gonzales (2018), who point to the damage caused by static and dynamic loads.

Mental load and psychosocial factors were found to be the least severe, which contrasts with the results of studies on heavy cargo transport (Buñay, 2020), suggesting that for the workers studied in the Mayan Train project, cognitive stress is secondary to the existing physical strain.

6. CONCLUSIONS

The findings of this assessment in the municipality of Escárcega, Campeche, make it clear that railroad workers operate under very high risk conditions. The consistency of the data obtained with previous studies reinforces the need for intervention, specifically in the control of the physical environment and schedule management.

The difference in risks between a laborer and a machine operator means that solutions cannot be general, but must be specific to each task. The LEST method shows that, although regulatory compliance in large projects is often a challenge, it is possible to identify specific failures to prevent the gradual deterioration of personnel health. Without immediate corrective measures, fatigue, musculoskeletal injuries, accidents, illnesses, among others, will continue to be commonplace in this type of work.

Considering the characteristics found in the work environment and jobs evaluated in this study, the following recommendations are issued:

a). Time management and breaks: It is a priority to limit consecutive long working hours. Mandatory breaks for hydration and stretching should be established to prevent physical fatigue from causing accidents.

b). Environmental safety: Given that temperatures in the region reach 40°C, providing fresh, purified drinking water should be mandatory and essential for carrying out daily work. Likewise, rest areas should be set up that provide real shade and ventilation, and staff should be rotated during the hours of peak solar radiation. The use of hearing protection must be strictly supervised, not just provided.

c). Safety in operations and conduct: The work area must be marked immediately and the use of PPE reinforced. It is important to implement controls on alcohol consumption, as well as to provide training in the handling of manual loads and support for coping with stress resulting from isolation and long working hours.



Figure 4
Worker carrying a log.



Figure 5
Workers digging trenches.

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ANALYSIS OF THE DEVELOPMENT OF ERGONOMICS IN THE CUBAN WORKPLACE DURING 2010-2025

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Abstract: The objective of this research is to analyze the development of ergonomics in Cuba based on a literature review covering the period 2010-2025. The PRISMA method and VOSviewer software were used to search for and view articles from Scopus, Scielo, Latindex, and Cuban university repositories. A total of 120 articles were analyzed, with the main results being: the year with the highest number of research studies was 2022, the database with the highest representation was Scielo, and the most prominent dimension of ergonomics was organizational ergonomics. Despite being a developing country, Cuba has made great strides in ergonomics, making it one of the Latin American countries with the greatest contributions to the field.

Keywords: Cuba, Ergonomics, Development of Ergonomics, Prisma Method, literature review

Relevance to Ergonomics: Provides an updated bibliometric analysis (2010-2025) of the development of ergonomics in the Cuban workplace. Identifies that organizational (34.04%) and physical (28.72%) ergonomics are the most studied dimensions in Cuba. Documents relevant Cuban regulatory advances, such as the inclusion of psychosocial factors in labor legislation and the work towards implementing ISO 45001/45003 standards. Highlights the central role of the University of Matanzas as a hub for training and research (master's degree, laboratory, specialized journal).

1. INTRODUCTION

Ergonomics is defined by the International Ergonomics Association (IEA) as the “...scientific discipline concerned with the understanding of interactions between humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design for the optimization of human and overall well-being” (Gómez Salazar, 2022).

Torres and Rodriguez (2021) note that studies related to ergonomics date back several centuries, but it was not established as a scientific discipline until the late 1940s. During that period, important associations dedicated to ergonomics were founded, such as the Human Factors and Ergonomics Society (HFES) in the United States, the International Ergonomics Association (IEA) in 1961, and the Société d'Ergonomie de Langue Française (ELF) in 1963. Today, the IEA comprises more than 50 ergonomics societies from different regions of the world, reflecting its global development and reach.

In Cuba, according to Torres et al. (2013), the term “ergonomics” became established on the island in the 1970s thanks to the introduction of the concept into postgraduate studies by Professor Ángel Portuondo. The academic foundation of ergonomics in the country was established with the doctoral theses of Vicente López, on thermal comfort in subtropical climates, and Silvio Viña, on physiological and ergonomic aspects of agricultural work, supported by Polish experts and institutions in the socialist context of that time. However, the first doctoral thesis on ergonomics in Cuba was that of Professor Joaquín García in 1988, which dealt with mental workload in the sugar industry.

During these years and in the early 2000s, several Cuban magazines were created that published articles on topics related to ergonomics, such as the Cuban Journal of Health and Work and the Industrial Engineering magazine from the José Antonio Echeverría Higher Polytechnic Institute (CUJAE). According to Montero and Viña (1995), several institutions studying ergonomics were created in Cuba, with five industrial engineering faculties in the country in 1995: the Institute of Industrial Design, the Institute of Occupational Medicine (now the National Institute of Workers' Health), the Faculty of Psychology and Biology, the Institute for Labor Studies and Research, the Institute of Physical Culture, and the Institute of Sports Medicine.

Currently, this field is studied in Cuba within the discipline of Human Factors Engineering in the Industrial Engineering and Industrial Design programs. In addition, there is a Master's Degree in Ergonomics, Safety, and Occupational Health at the University of Matanzas, and at one time it was also offered at the José Antonio Echeverría Technological University of Havana (CUJAE), which has a multidisciplinary faculty and different professionals from all over Cuba.

The objective of this research is to analyze the development of ergonomics in the Cuban labor context through a bibliometric analysis in the period 2010-2025.

2. METHODOLOGY

The PRISMA method was applied to search and analyze articles in Scopus, Scielo, Latindex, and Cuban university repositories, using the approach described by Acosta Prieto et al. (2024). The search for articles focused on answering the following questions:

What is the focus of research on ergonomics in Cuba?

What are the advances in ergonomics in Cuba?

For this review, articles published between 2010 and 2025 were selected, prioritizing scientific research published in journals or institutional repositories. Only works written in Spanish or English were included, ensuring the relevance and pertinence of the content to the research question posed. Additionally, only open-access publications were considered, facilitating the consultation and comprehensive analysis of the available scientific information.

Documents that presented information irrelevant to the study objective were excluded from this review, as were articles related to conference proceedings, book chapters, and entire books. Similarly, publications written in languages or time periods other than those specified were also excluded. Figure 1 reflects the procedure used to identify, review, and select the scientific papers used for this research.

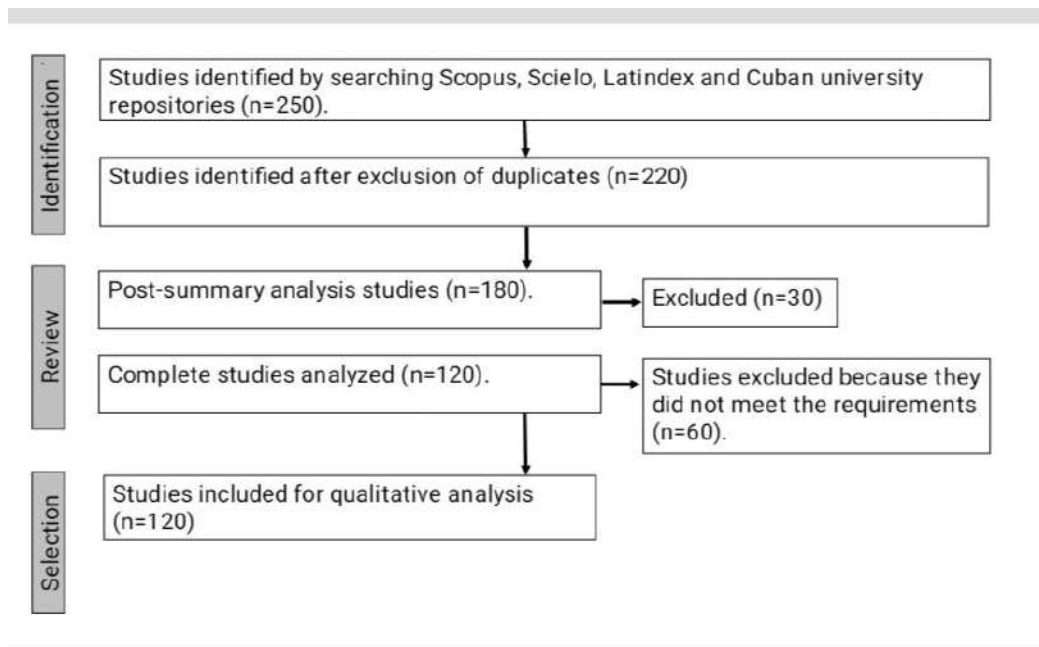


Figure 1 Procedure used through the Prisma method

3. RESULTS

Figure 2 shows the number of articles published per year in the period 2010-2025 out of the total number of studies analyzed on ergonomics in Cuba. The figure shows a clear upward trend, with 2022 standing out with more studies conducted on ergonomic topics, with a total of 22 studies making up 16,6% of the sample analyzed. In addition, we can observe an increase in the study of ergonomics in Cuba over the last five years.

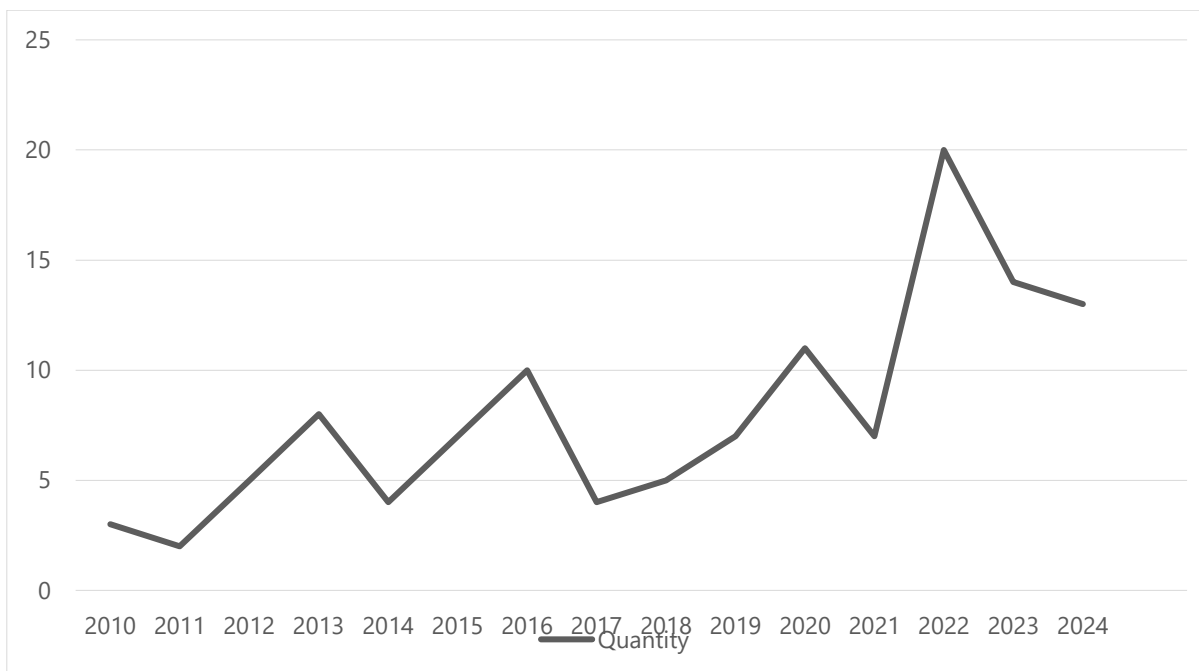


Figure 2. Count of articles on ergonomics published in Cuba.

Figure 3 shows the sources of the research analyzed, where the highest concentration is found in Scielo (53.19%), followed by institutional repositories (19.15%).

Figure 4 shows the dimensions of ergonomics investigated in the sample analyzed. The most studied dimension is organizational ergonomics (34.04%), followed by physical ergonomics (28.72%). It is not yet considered a dimension of ergonomics because it focuses on research from the point of view of occupational health and safety as psychosocial risk management, so it was not taken into account for the graphergonomics (28.72%). In the case of psychosocial ergonomics,

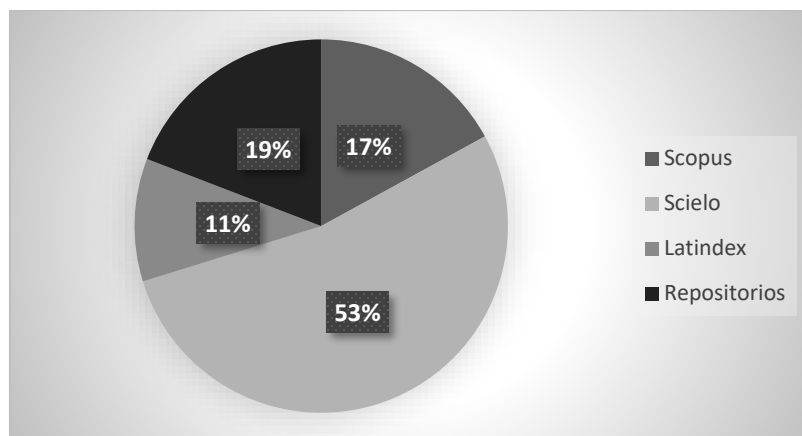


Figure 3. Sources of research on ergonomics in Cuba

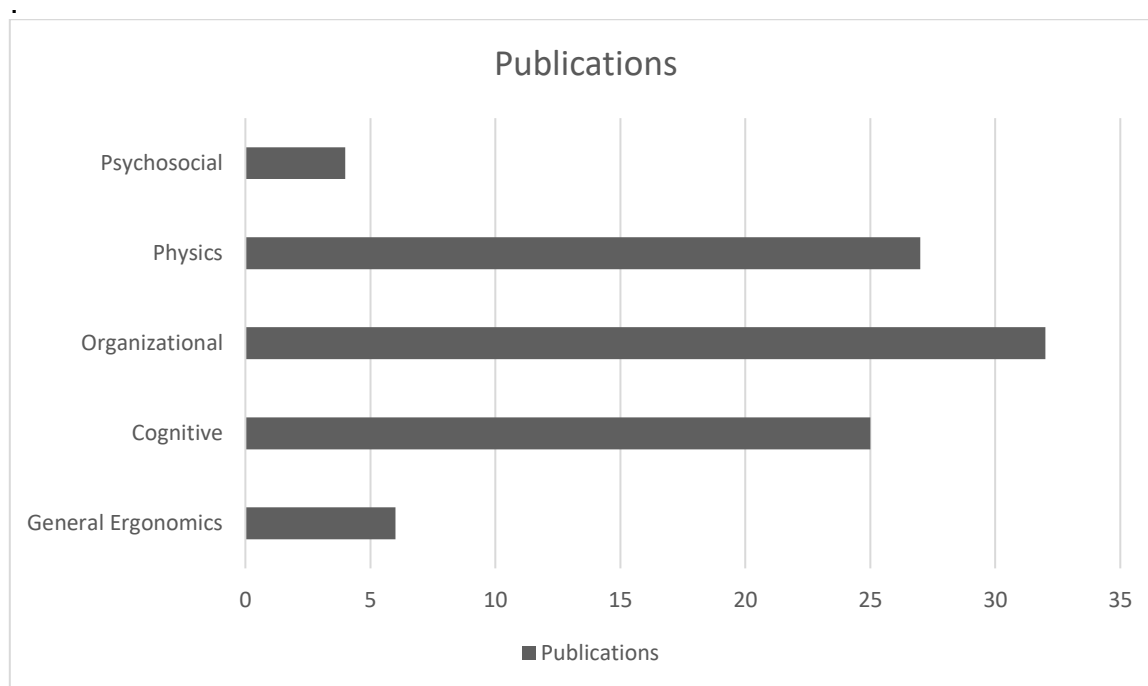


Figure 4. Types of ergonomics studied in Cuba.

Despite being a developing country, Cuba has demonstrated that, over the last ten years, research on ergonomics has placed it at a satisfactory level, although it still faces many challenges. Based on the sample of Cuban studies on this subject analyzed, it can be seen that there is a strong incentive to improve working conditions through the

organization of work, analysis of noise levels, lighting, posture, and anthropometric design, mental workload, and work-related stress, among other factors.

In order to understand the evolution and current state of ergonomics research within the

Cuban labor context, a detailed analysis of scientific literature published between 2010 and 2026 was conducted. Table 1 presents a summary of 25 selected studies, ranging from pioneering research in key sectors such as tourism and health to recent methodological developments and the application of novel approaches such as cognitive ergonomics and the study of the informal sector. The table is organized chronologically to facilitate the visualization of the thematic progression and deepening of the discipline in the country. For each study, the authors, year of publication, central theme of the research, and its main contribution to the development of ergonomics in Cuba are specified.

Table 1 Summary of the main studies on ergonomics in the Cuban workplace (2010-2025)

Author (Year)	Research Topic	Contribution of the research
Real Pérez et al. (2010)	Application of a procedure for the identification, evaluation, and control of MSDs in chambermaids in the hotel sector of Varadero	It uses a combination of methods (body map, analysis of medical certificates, RULA method) to establish a solid diagnosis and proposes an intervention program with practical and participatory measures.
Rodríguez Ruíz y Guevara-Velasco, (2011)	Evaluation of workstations in a Mexican company using the ERIN and RULA methods, and comparison of the results with disease statistics.	Although the study was conducted in Mexico, it is relevant because it validates the combined use of ERIN and RULA, demonstrating their usefulness for the prevention of MSDs. Furthermore, the authors of the article (Rodríguez Ruíz) are Cuban references in the development of evaluation methods (ERIN), which connects Cuban research with the international context.
Rodríguez Ruíz et al. (2012)	Proposal of a maturity model (Ergonomics Maturity Model for Companies - EMMC) to assess a company's capacity to implement ergonomic programs.	Develops a macro-ergonomic tool of great practical value. The EMMC allows Cuban companies to self-assess across five maturity levels (from "Ignorance" to "Innovative") and outline strategies to progressively and systematically integrate ergonomics into their management, aligning it with business objectives.
Coureaux Rojas et al. (2013)	Identification of the prevalence of spine disorders in stomatologists with more than 10 years of experience.	Provides empirical evidence of the high incidence of musculoskeletal disorders (MSDs) in Cuban stomatologists, directly linking them to forced postures and the lack of ergonomics in the workplace. Serves as a basis to justify preventive interventions in the health sector.
Díaz Gutiérrez et al. (2013)	Description of MSDs in stomatologists and assessment of their knowledge of ergonomic principles.	Confirms the high prevalence of MSDs (neck, back, shoulders) in Cuban stomatologists and, crucially, reveals a high level of lack of knowledge (87.6%) about ergonomics among professionals. This finding underscores the urgent need to include

		ergonomic training in undergraduate and postgraduate curricula.
Rodríguez Ruíz, & Pérez Mergarejo, (2013)	Proposal of a general ergonomic intervention procedure for Cuban companies, emphasizing the need to justify proposals to management.	Provides a standardized and easy-to-understand procedure to guide occupational health and safety professionals in implementing ergonomics. Its main contribution is highlighting the importance of "Step 4: Evaluation of proposals" (including cost-benefit analysis) as a key element to convince management and ensure the implementation of improvements.
Nariño Lescay, (2015)	Characterization of the importance of having updated anthropometric data of the current Cuban working population for social development.	Provides a solid theoretical and social foundation for the need for specific anthropometric data. It exposes the problems of population aging and the high incidence of MSDs due to poor workplace design, justifying the urgency of conducting national anthropometric studies to adapt work to humans and improve productivity and health.
Crespo Almeida et al. (2016)	Analysis of the relationship between postural attitude and environmental conditions (environmental ergonomics) in physical activity.	Provides a conceptual framework that integrates environmental ergonomics with postural biomechanics, offering practical principles of body mechanics applicable to various work contexts in Cuba, beyond the sports field for which it was written.
Nariño Lescay et al. (2016)	Review of technologies for capturing anthropometric data and assessment of their applicability in the Cuban context.	Conducts a critical analysis of anthropometric measurement technologies (from manual to 3D scanners), concluding that, given Cuba's economic limitations, photogrammetry (measurement by photography) is the most viable, accurate, and low-cost technology for conducting local anthropometric studies.
Sánchez Vidal et al. (2016)	Identification of signs and symptoms affecting the health of office workers using display screen equipment (DSE) in an academic institution.	Addresses ergonomics from a health promotion perspective, a fundamental approach for primary prevention. It identifies a high prevalence of MSDs and visual fatigue, associating them with non-compliance with basic ergonomic principles and a lack of knowledge among workers, which justifies educational and workplace redesign actions.
Rodríguez Ruíz & Pérez Mergarejo (2016)	Review of technologies for capturing anthropometric data and assessment of their applicability in the Cuban context.	Conducts a critical analysis of anthropometric measurement technologies (from manual to 3D scanners), concluding that, given Cuba's economic limitations, photogrammetry (measurement by photography) is the most viable, accurate, and low-cost technology for conducting local anthropometric studies.
Ferrer Colina (2017)	Design and implementation of a procedure for work organization studies in technical-administrative positions at a telecommunications company.	Offers a detailed case study on the application of work organization in the service sector. It demonstrates how work measurement (time study) and workload analysis allow for workforce optimization, service improvement, and decision-making regarding the opening of new points of sale without increasing staff.

Mejias-Herrera, (2018)	Analysis of the conceptual bases of macro-ergonomics and presentation of a macro-ergonomic intervention procedure developed and applied in Cuba.	Provides a high-level (macro-ergonomic) view of the analysis of work systems in Cuba. The presented procedure, which integrates systemic diagnosis, participation at all levels, and results evaluation, has been successfully applied in sectors such as biotechnology and telecommunications, demonstrating improvements in the quality of work life and productivity.
Real Pérez et al. (2019)	Evaluation of work and rest regimes (WRR) in hotel workers (reception, chambermaids, waiters) in Varadero.	Addresses a fundamental aspect of work organization. Through surveys, the Yoshitake Test, and the ILO method, it demonstrates that WRR are established arbitrarily and do not meet the real needs of workers, proposing adjustments in the total rest time and its distribution for each position.
Pacheco León et al. (2021)	Design and application of a procedure integrating ergonomics and work organization to improve the room cleaning service in hotels.	Demonstrates, with concrete data, how an ergonomic intervention (redesign of furniture and tasks) not only improves workers' health (reduces absences due to MSDs) but also increases productivity and organizational efficiency. It is a success story that justifies investment in ergonomics.
Acosta Prieto et al. (2022)	Socioeconomic assessment of an occupational risk intervention program in a railway repair workshop, using the Socioeconomic Index (SEI).	Applies and validates the Socioeconomic Index (SEI) in a Cuban industrial context. This tool integrates cost-benefit analysis with Intangible Social Costs (ISC). This approach allows for prioritizing investments in health and safety not only based on economic profitability but also on the perception and willingness of the workers themselves to pay to eliminate the risks that most affect them.
Almeda-Barrios et al. (2022)	Development and validation of an integrated technology for environmental and occupational noise management in sun and beach hotels in Varadero.	Provides a pioneering methodological tool in Cuba to address noise not just as a pollutant, but as a risk to be managed. It integrates the creation of noise maps, the design of control measures (primary, secondary, and organizational), and their validation, improving the acoustic comfort of workers and guests.
Cuesta-Santos et al. (2022)	Scientific-technical foundation for the Cuban regulation on teleworking and remote work (Resolution 71/2021).	Represents a milestone in organizational and legal ergonomics in Cuba. By underpinning Resolution 71/2021, it incorporates, for the first time in a national standard, ergonomic and occupational health and safety requirements for teleworking, including the consideration of psychosocial risks and the need for an adequate design of the home workspace.
González Betancourt et al. (2022)	Determining the essential elements of an interdisciplinary, humanistic, active, and transformative (IHAT) approach in the prevention of occupational diseases for sustainable development.	Proposes a novel theoretical-methodological framework integrating medicine, law, and ergonomics for the prevention of occupational diseases. The IHAT approach empowers the worker as an active subject in their self-care and health self-management, aligning with new forms of work organization (teleworking, non-state sector) and the sustainable development goals in Cuba.

Milian-Menendez & Zaldivar-Salazar, (2022)	Evaluation of the level of satisfaction of urban bus drivers with the design of their workplace.	Identifies, through a survey of 60 drivers, the main parameters of dissatisfaction (air conditioning, isolation, pedal reach, seat suspension). This study provides valuable and objective data to support the redesign of driver workstations, both for imported buses and those produced in the country, to improve driver health and safety.
Contreras-Rodríguez et al. (2023)	Analysis of postural risks in hotel bartenders using the BPD and REBA methods. .	Applies a combined approach (perception of discomfort and objective evaluation) to demonstrate the high ergonomic risk in an understudied job position in the tourism sector, justifying the need for interventions to prevent MSDs.
Rodríguez Santana et al. (2023)	Improvement of work organization in the coffee roasting process using the General Problem-Solving Method (GPSM).	Applies an integrated approach (Methods Engineering and Ergonomics) to diagnose the causes of production non-compliance. It identifies multiple risk factors (microclimate, noise, lighting, work method, anthropometric design) and proposes potential solutions, demonstrating the usefulness of the GPSM for process improvement in the Cuban food industry.
Mac Cabreja et al. (2024)	Identification of ergonomic risks and occupational diseases in pneumatic drill operators in the construction sector.	Addresses a high-physical-demand job in a key economic sector. It uses methods such as REBA and G-INSHT to diagnose a "High" and "Non-Tolerable" risk, respectively, and proposes an action plan with concrete measures (engineering, organizational, and personal protective equipment) to mitigate the risks and associated diseases (low back pain, tendinitis).
Pancorbo Camacho et al. (2025)	Diagnosis of physical and cognitive ergonomic risks in university logistics workers.	Applies a dual approach (physical and cognitive) that is uncommon in Cuba, using methods such as the step test and the analysis of psychophysiological indicators. It reveals physical overload in warehouse assistants and moderate mental workload in administrative positions, allowing for specific and personalized interventions.
Rodríguez Reyes et al. (2025)	Investigation of the main ergonomic risk factors (biomechanical and environmental) in informal seamstresses in Cuba.	It is a pioneering study in Cuba for addressing the informal sector, an area of great vulnerability and little research. It uses methods such as RULA, the Corlett and Bishop diagram, and digital applications to diagnose postural and lighting risks, proposing a plan of low-cost and practical measures to improve working conditions at home.

4. DISCUSSION

This literature review, summarized in Table 1, allows us to draw up a roadmap for the development of ergonomics in Cuba in the period 2010-2025. The chronological analysis of the 25 studies reveals a clear evolution from an approach initially focused on the diagnosis of musculoskeletal disorders (MSDs) in priority economic sectors to a more mature discipline that integrates cognitive, organizational, and environmental

dimensions and addresses diverse and complex work contexts, including the development of tools for the management and prioritization of interventions.

In the Cuban context of physical ergonomics, the use of the Rula y Reba method with the help of Kinovea software stands out for postural analysis, the design of safe and inclusive workstations for people with disabilities, the assessment of physical work capacity in jobs involving high muscular activity, such as the fire department, and research that challenges existing economic challenges and develops robotic exoskeletons for certain areas such as public health. In Gonzales Verde's (2021) research, using the Reba method, Cornell questionnaires, filming, and video analysis with Kinovea software, he analyzes the ergonomic postural risks in EMPERCAP's CUPET-3 Oil and Gas Well Drilling Team.

In addition, in Cuba, there is research where artificial intelligence was used with the ErgoIA program for postural assessment, as evidenced in the research by Cuello Cuello et al. (2024). Likewise, on the island, several studies focus on occupational risk management, such as noise and musculoskeletal disorders, as evidenced in the doctoral theses of Almeda (2022) and Real Pérez et al. (2011).

Cognitive ergonomics in Cuba is developed to a greater extent in the assessment of mental load and human error in certain jobs and even in university students, using methods such as biomolecular, physiological, psychophysiological, and psychological indicators. Such is the case of the research carried out by Acosta Prieto (2022), which evaluates mental load in industrial engineering students at the University of Matanzas, where tests were carried out to measure these indicators before and after cognitive activities. In addition, Acosta Prieto (2023) created a technology for managing mental load in jobs with cognitive demands, which was applied in Cuban entities as a result of his doctoral thesis.

Organizational ergonomics in Cuba, as previously mentioned in this research, is one of the most studied dimensions of ergonomics on the island, where they present analyses of thermal comfort, work organization, and methods engineering, among others.

In his research, Lazo (2024) evaluates thermal comfort at the Cienfuegos printing company using the Fanger method, where six of the nine premises analyzed exceeded 55% thermal dissatisfaction. He proposes technical measures such as ventilation and air conditioning, organizational measures such as breaks and task rotation, and personal protection measures such as acclimatization and periodic medical checks.

During the pandemic, ergonomic knowledge was used to address biological, chemical, physical, ergonomic, and psychosocial risks to workers, especially in healthcare and other sectors exposed to contagion. The study by Gamboa Díaz et al. (2021) emphasized the importance of preventive measures in the workplace, including teleworking, use of personal protective equipment, hygiene, physical distancing, health monitoring, and strategies to preserve mental health. These measures were applied in the Cuban plan to prevent contagion and protect the health of workers during the gradual return to work activities.

In Cuba, the ongoing work to implement ISO 45001:2018 in all companies has intensified in recent years. This has allowed Cuban companies to prioritize the implementation of emerging standards to improve all aspects of business management,

such as ISO 45003:2022, which provides guidelines for managing psychosocial risks at work.

Cuba has participated in certain advances in the area of psychosocial ergonomics. This is demonstrated by Law 151 of the Penal Code, approved in 2022, which includes provisions that protect workers from situations that may affect their psychosocial well-being, such as workplace harassment and malicious violation of labor and social security rights. In addition, Decree 39/2023 has been approved, which is a protocol for action against discrimination, violence, and harassment in the workplace that seeks to guarantee safe and healthy working environments, promoting conditions of equality and equity. An update to the Labor Code is currently being drafted to adapt it to the existing working conditions in the country, promoting terms relating to multiple employment, remote work, teleworking, and protection for workers in the non-state sector, among others.

In addition, legislation was enacted that includes psychosocial factors as part of the occupational risks that workers may face, and Resolution 7 of Official Gazette No. 10 of the Republic of Cuba was approved by the Ministry of Labor and Social Security (2021), providing for additional pay for workers who are exposed to special conditions in the workplace.

From a professional training perspective, Cuba has an ergonomics laboratory at the University of Matanzas (the only one in the country), and the same university offers a master's degree in ergonomics, safety, and occupational health with a category of excellence. This same institution developed the first magazine in Cuba that deals exclusively with topics related to ergonomics, called *Desafíos Ergonómicos* (Ergonomic Challenges), which is a space for researchers studying this branch of science. In addition, this discipline is part of the industrial engineering degree program offered at Cuban universities, postgraduate courses, and a module in the Master's Degree in Industrial Engineering and Systems at the José Antonio Echeverría Technological University of Havana (CUJAE).

5. CONCLUSIONS

This research reveals the significant development of publications and studies on ergonomics in Cuba, highlighting the last five-year period. In addition, it highlights the influence of universities in encouraging research on this topic on the island, where 19.15% of the studies analyzed come from institutional repositories. While in the international context there is a trend toward studies that analyze Industry 4.0 and 5.0, in Cuba research focuses mainly on classic ways of identifying and solving ergonomic risks. This gap in methodologies and tools for ergonomic analysis does not prevent Cuban researchers from continuing to search for new ways to ensure that work is adapted to human conditions, creating safe and healthy work environments. Given these differences, the use of international methodologies in the Cuban context requires careful analysis in order to achieve an effective impact.

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WORKING WOMEN AND PELVIC FLOOR DYSFUNCTIONS FROM AN OCCUPATIONAL ERGONOMICS PERSPECTIVE

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Resumen: Se estima que del 20% al 50 % de la población femenina mundial padece de incontinencia urinaria (Trapani et al., 2025) y cerca del 20% experimentará algún grado de prolapso de órganos pélvicos (Si et al., 2024). Las mujeres trabajadoras pueden presentar algunas de estas condiciones, por lo tanto, el objetivo de la revisión de la literatura científica fue describir las experiencias laborales de las mujeres trabajadoras en función de sus exigencias de trabajo y quiénes de ellas presentan disfunciones del piso pélvico. **Metodología:** Revisión bibliográfica en PubMed, ScienceDirect, Scopus y Taylor & Francis de mujeres trabajadoras con disfunciones del piso pélvico del periodo 2010 a 2025, la selección de la literatura fue por conveniencia para destacar las condiciones de trabajo, aspectos ergonómicos organizacionales, las demandas de trabajo, así como las narraciones de las propias trabajadoras para describir su jornada laboral. **Resultados:** Se identifican estudios transversales y de revisión que muestran una dinámica bidireccional entre las disfunciones del piso pélvico y el trabajo, se reconocen asociaciones entre las demandas físicas, la organización del trabajo y la presencia de disfunciones, así como la presencia de disfunciones del piso pélvico como generador de estrés y cambios en la capacidad laboral. Las principales ocupaciones investigadas son enfermería, fuerzas militares, trabajadoras rurales y operarias (Brock et al., 2024; Markland, Chu, Epperson, et al., 2018) **Conclusión:** La recopilación y análisis de estas investigaciones contribuyen a la ergonomía ocupacional con un enfoque de género e identifican temas que requieren mayor investigación para promover la salud del piso pélvico de las mujeres trabajadoras.

Palabras clave: Disfunciones de piso pélvico, ergonomía ocupacional, género, mujeres trabajadoras

Relevancia para la ergonomía: Fortalecer el abordaje ergonómico con un enfoque de género de índole aplicativo en los ámbitos laborales que contextualice la diversidad de situaciones experimentadas por las mujeres por adaptarse a las exigencias de trabajo, que en este caso el foco de atención fue la salud del piso pélvico femenino. Esta revisión contribuye significativamente a los alcances de la

literatura científica sobre disfunciones del piso pélvico desde una perspectiva ergonómica ocupacional.

Abstract: Introduction: It is estimated that 20% to 50% of the world's female population suffers from urinary incontinence (Tapani et al., 2025), and approximately 20% will experience some degree of pelvic organ prolapse (Si et al., 2024). Working women may experience some of these conditions; therefore, the aim of this literature review was to describe the work experiences of women in relation to their job demands and to identify those who present with pelvic floor diseases. **Methodology:** A literature review was conducted in PubMed, ScienceDirect, Scopus, and Taylor & Francis on working women with pelvic floor diseases from 2010 to 2025. The literature was selected for convenience to highlight working conditions, organizational ergonomic aspects, job demands, and the workers' own narratives describing their workday. **Results:** Cross-sectional and review studies were identified that show a bidirectional dynamic between pelvic floor dysfunction and work. Associations were recognized between physical demands, work organization, and the presence of dysfunction, as well as the presence of pelvic floor disorder as a source of stress and changes in work capacity. The main occupations investigated were nursing, military personnel, farmworkers, plant operators (Brock et al., 2024; Markland, Chu, Epperson, et al., 2018). **Conclusion:** The compilation and analysis of this research contributes to occupational ergonomics with a gender focus and identifies topics that require further investigation to promote pelvic floor health in working women.

Keywords: Gender, occupational ergonomics, pelvic floor disorder, working women

Relevance to ergonomics: Strengthening the ergonomic approach with a gender-sensitive, applied perspective in the workplace, contextualizing the diverse situations experienced by women adapting to work demands, in this case focusing on the health of the female pelvic floor. This review significantly contributes to the scope of scientific literature on pelvic floor dysfunctions from an occupational ergonomics perspective.

1. INTRODUCTION

Women are considered a fundamental pillar for the economic development of Latin America (World Bank, 2025). Increasingly, women are participating in the paid labor market, especially in the service sector, primarily occupying operational positions with limited participation in senior management, thus perpetuating the gender gap (International Labour Organization, 2025). Research on the health and illness of working women highlights musculoskeletal disorders (Dahlgren et al., 2025), risk factors during pregnancy (Almohammed et al., 2024; Liang et al., 2024), menopause (Walker-Bone & Davis, 2025), and breastfeeding (McCardel et al., 2024; Türkmen et al., 2025), among others. While some physiological and biological characteristics

are considered, there is a noticeable lack of specific research topics focused on working women.

Notably, the abdomino-lumbo-pelvic-perineal anatomy of women is very different from that of men, given the functions of the reproductive system. The pelvic floor is made up of muscular structures, ligaments, and fascia, which provide structural support and are involved in urinary, sexual, reproductive, and defecation functions, as well as in functions such as abdomino-lumbo-pelvic stability and respiration (Pérez Rodríguez NM, 2025). Due to their biological characteristics, women are more vulnerable to having the functions of the pelvic floor structures affected, leading to dysfunctions. Defined as a broad set of symptoms and anatomical changes related to abnormal function of the pelvic floor muscles and tissues, the symptoms are: lower urinary tract infections, urinary incontinence (stress, urge, mixed), pelvic organ prolapse, fecal incontinence and pelvic pain, all of which have a multifactorial etiology and affect, to a greater or lesser extent, the quality of life of women (J. Lin et al., 2025; Wu et al., 2023).

The most common symptoms are urinary incontinence and pelvic organ prolapse. Urinary incontinence affects 24% to 45% of the world's female population (Leslie et al., 2024). It is the involuntary leakage of urine and is classified into stress, urge, and mixed types. Its multifactorial etiology includes demographic, lifestyle, comorbid, and obstetric-gynecological risk factors. Urinary incontinence negatively impacts physical, psychological, social, and financial well-being (Trapani et al., 2025). Pelvic organ prolapse (POP) is the descent of the pelvic organs into or beyond the vaginal opening when the pelvic floor becomes too weak to support them. The prevalence of symptomatic POP increased from 1.8% in women in their twenties to 19.2% in women aged seventy and older (Si et al., 2024). DeLancey developed a conceptual model to study the morphological changes in prolapse related to age and parity, contributing to the understanding of the particular morphological and anatomical characteristics of the female pelvic floor (J. O. DeLancey et al., 2024). Additionally, she created a graphical representation of the causal factors of pelvic floor disorders, highlighting the importance of women's physical activity levels and age; the higher the levels of physical activity, the more rapidly pelvic floor dysfunctions may appear in a woman's life (J. O. L. DeLancey et al., 2008).

Publications have been identified that present approaches to the symptoms of pelvic floor dysfunction and work, in nurses (Gomes Lopes et al., 2019), athletes (Giagio et al., 2021), military personnel (Freire et al., 2023), and female factory workers (Woodman et al., 2006). These studies have identified a prevalence and increase in symptoms due to work-related activities. A few other investigations have identified the difficulties of returning to work activities after pregnancy and childbirth due to the condition of their pelvic floor (Schytt et al., 2004, 2005). Given that

Ergonomics is “the scientific discipline concerned with understanding the interactions between humans and other elements of a system” (International Ergonomics and Human Factors Association, 2023), it is considered valuable to expand the analysis of working women and pelvic floor dysfunctions from the perspective of occupational ergonomics.

2. GENERAL OBJECTIVE

To describe the scientific evidence of the work experiences of female workers who present pelvic floor dysfunctions, reported from 2010-2025 in order to contribute risk prevention actions for health care from an occupational ergonomics perspective.

3. METHODOLOGY

A narrative review was conducted to synthesize the existing evidence on the relationship between working conditions, from an occupational ergonomics perspective, and pelvic floor dysfunction in women. A systematic search was performed in the PubMed, ScienceDirect, Scopus, and Taylor & Francis databases, limiting the publication period to between 2010 and 2025 to ensure the currency of the findings.

3.1 SELECTION CRITERIA AND PROCEDURE

Controlled descriptors (MeSH/DeCS) were combined using Boolean operators: (occupation OR work OR "woman working") AND ("pelvic disorder" OR "urinary incontinence" OR "lower urinary tract symptoms" OR "pelvic prolapse"). The initial search yielded 1,197 records, which were managed in Mendeley for duplicate detection (Table 1).

Table 1. Boolean operators		
Database	Search equation	Results
Taylor & Francis	(Occupation OR Women, Working) AND "urinary incontinence"	408
	(Occupation or work) AND "pelvic prolapse"	123
Pubmed	(Occupation or work) AND "Lower Urinary Tract Symptoms"	76
	(Occupation or work) AND "pelvic prolapse"	15
Science Direct	(Occupation or Women, Working) AND "urinary incontinence"	234
Scopus	"Occupation AND Lower Urinary Tract Symptoms"	41
	(Occupation or work) AND pelvic prolapse	300

Table 1. Boolean operators

Note: Searches were limited to peer-reviewed literature from 2010-2025 to ensure the validity of the evidence in the field of ergonomics.

After excluding 112 duplicate articles, an initial screening of 1,085 titles was performed. Following a selection process based on relevance, 23 documents were selected for full-text review. The inclusion criteria required that the studies explicitly integrate variables related to organizational ergonomics, job demands, working conditions, and/or qualitative narratives from female workers about their workday.

It is worth noting that the term 'Ergonomics' was not included as a restrictive descriptor in the initial search equations. This methodological decision was based on the need to maximize the sensitivity of the search, avoiding the bias of excluding studies that, while analyzing ergonomic determinants (such as biomechanical demands, organizational factors, or working hours), do not use the taxonomic term in their keywords. Thus, the ergonomic dimension was integrated as a qualitative eligibility criterion during the full-text review phase, ensuring a more holistic capture of the available evidence.

4. RESULTS

Occupational ergonomics is defined in this research as the multidimensional study of human capabilities and limitations in relation to the work system (International Ergonomics and Human Factors Association, 2023). In the context of the female pelvic floor, the analysis of the collected literature classifies the information into different domains: physical ergonomics (physical load, postures, and load handling), integrating organizational ergonomics (time management and urination breaks) and cognitive ergonomics (perception of workload and effort narratives). Table 2 summarizes the author's information, the research design, the variable studied, and the findings that highlight the urgent need for attention to the pelvic floor health of working women. A descriptive analysis of the areas of ergonomics, and primarily the contributions of occupational ergonomics, follows.

1. Physical Ergonomics

This domain focuses on the interaction between human anatomy and biomechanical capabilities in response to physical activity. In the workplace, it encompasses the analysis of awkward postures, manual handling of loads, and repetitive movements (J. O. Gomes, 2014). The evidence gathered links these physical demands to pelvic floor dysfunction, identifying manual handling and prolonged standing as the main risk factors.

Evidence in populations with high physical demands

Descriptive studies in populations with high physical demands, such as female military personnel, report a significant prevalence of urinary symptoms and pelvic organ prolapse (POP) (S. D. O'Shea et al., 2023). These findings coincide with meta-analyses that highlight the vulnerability of workers in the rural and nursing sectors (Addisu et al., 2023; Markland, Chu, Neill Epperson, et al., 2018). While these studies underline the need for research with greater statistical power, they establish a clear basis for occupational exposure in these sectors.

Causal relationship and pathophysiological mechanisms

A more rigorous longitudinal study (Carter Ramirez et al., 2022) establishes a causal relationship between frequent lifting and pushing of heavy loads and the development of pelvic organ prolapse (POP). The identified mechanism is that repetitive physical exertion acts as a chronic fatigue factor on the supporting structures (uterosacral ligaments and endopelvic fascia), recognizing some critical populations, such as agricultural workers (Addisu et al., 2023) and military personnel, where the lifting of heavy equipment is compounded by prolonged standing (Fransson et al., 2025; S. O'Shea et al., 2025).

Another highly relevant qualitative study describes how women feel "betrayed" by a body that no longer responds the same to physical exertion when returning to work after pregnancy; ergonomic demands that were normal before pregnancy become dangerous or limiting upon returning to work (Vesting et al., 2025). This highlights the importance of considering the anatomical and bodily characteristics of women after pregnancy when performing work activities.

Synergy of risk factors

Recent literature highlights that the risk is heightened when multiple biomechanical factors coexist. In military and agricultural personnel, the load of heavy equipment does not act in isolation, but rather adds to the neuromuscular fatigue resulting from prolonged standing (Addisu et al., 2023; Fransson et al., 2025). This combination of static and dynamic loading accelerates the loss of integrity of supporting tissues, especially in women with a history of chronic pain, where core neuromuscular coordination may already be compromised (Fransson et al., 2025).

2. Cognitive ergonomics

This domain refers to perception, memory, reasoning, and motor response, and how these affect interactions between workers and other elements of the system. Relevant topics include mental workload, decision-making, expert performance, human-computer interaction, human reliability, stress, as well as training and its relationship to human system design. (J. O. Gomes, 2014) The collected scientific literature shows a relationship between stress and lower urinary tract symptoms and incontinence, in addition to distraction at work due to urinary symptoms.

Several cross-sectional studies, primarily conducted in Asia, have found, on the one hand, an association between high levels of work-related stress and the presence of urogenital infection symptoms in female workers (Sznajder et al., 2014), and on the other hand, a relationship between urinary urgency and elevated levels of anxiety and perceived stress (Lee & Park, 2023). A study of nurses reports that high work-related stress is associated with a "multiple urinary symptoms" profile (Gao et al., 2024). This suggests that mental workload also affects the pelvic floor.

Additionally, a systematic review of working women with urinary symptoms refers to a decrease in work performance capacity due to symptom-related distraction (K. Y. Lin et al., 2018), and a cohort study in Finland reports that urinary incontinence (especially urge and mixed urinary incontinence) significantly reduces physical and mental capacity for work (Salo et al., 2023). These studies support the assertion that urinary symptoms affect concentration and the performance of work activities.

3. Organizational ergonomics

Organizational ergonomics refers to the optimization of socio-technical systems, including their organizational structures and political processes. Relevant topics in this dimension include communication, crew resource management, job design, work hours/shift design, teamwork, participatory design, community ergonomics, cooperative work, new work paradigms, virtual organizations, teleworking, and quality management, among others. (J. O. Gomes, 2014).

The convergence of studies (Brady et al., 2026; Kim & Kwak, 2017a) reinforces the idea that pelvic floor health is mediated by organizational ergonomics. Dynamics that restrict access to the bathroom or work environments that do not facilitate bathroom access are critical predictors of long-term dysfunction. The inability to regulate bladder emptying due to the demands of the production line or customer service perpetuates harmful adaptive behaviors, ultimately impacting job retention and productivity (Pierce et al., 2017; Porto et al., 2025; Brock et al., 2024). Studies in the military (S. O'Shea et al., 2025), nursing (Lopes et al., 2019), and

manufacturing (Brady et al., 2020) reveal a critical organizational ergonomic behavior: female workers stop drinking water or hold their urine, "postponing urination" (infrequent voiding) to avoid interrupting workflow, due to high patient care demands, lack of relief staff, or inadequate facilities, resulting in "occupational bladder." This behavior leads to overdistension of the detrusor muscle and increases the prevalence of urge urinary incontinence and lower urinary tract symptoms (LUTS).

Other domains: occupational status and productivity

It is pertinent to mention two elements identified in the literature that are not explicitly and independently part of the ergonomics domains previously described: occupational status and productivity. Regarding occupational status, managerial and professional occupations were statistically associated with a lower risk of lower urinary tract symptoms and their impact, while employment in service positions was statistically associated with a higher risk (Brady et al., 2026). Similarly, another study shows a higher risk of urinary incontinence in service and sales jobs (with greater dynamic physical demands when performing the activities) compared to administrative jobs; occupational status acts as a social determinant of pelvic health (Kim & Kwak, 2017b). Beyond isolated biomechanical factors, recent evidence suggests that hierarchical structure and occupation type act as critical determinants of pelvic health.

Regarding the economic impact, Lin and Gomes (K. Y. Lin et al., 2018) (C. M. Gomes et al., 2020) make the "productivity" argument: pelvic floor dysfunctions not only cause pain but also cost companies money due to absenteeism and presenteeism (being at work but distracted by symptoms). Porto not only addresses health but also labor economics, demonstrating that a woman with severe incontinence symptoms is less productive at work, thus introducing the concept of presenteeism (Porto et al., 2025). Similarly, Vesting highlights the "unknown body" phenomenon in the postpartum period, where the lack of an adequate ergonomic transition upon returning to work can lead to chronic pelvic floor injuries (Vesting et al., 2025). This suggests that occupational ergonomics is not just an expense for the company but an investment in productivity.

Table 2. Studies from 2010 to 2025 of pelvic floor findings in female workers

Author/year	Studio Design	Population/Sector	Ergonomic variables: physical, organizational, cognitive	Pelvic floor finding (LUTS/IU/Other)
Lin et al. (2018)	Systematic Review and Meta-analysis	Working Women (General)	Work productivity and urinary symptoms.	Lower urinary tract symptoms (LUTS) are significantly associated with lost productivity. Impact on work performance due to symptom distraction. +1

Lee & Park (2023)	Cross-sectional study	Korean workers (192 subjects)	Occupational risk factors, perceived stress and mental health.+1	Stress urinary incontinence (SUI) is more prevalent in women than in men. Relationship between urinary urgency and elevated levels of anxiety and perceived stress.+1
Sznajder et al. (2014)	Cross-sectional study	Workers in export factories (China)	Occupational stress and conditions in factories.	30.9% reported symptoms of urogenital infection; 27.9% abnormal discharge.+2 Association between high levels of work-related stress and the presence of symptoms of urogenital infection.+2
Brady et al. (2025)	Cohort study (20 years)	Women (44-61 years old)	Physical: Manual labor. Organizational: Restricted opportunities to urinate.	Cumulative risk of developing moderate or severe urinary symptoms after years in high-risk occupations.+2
O'Shea et al. (2023)	Online cross-sectional survey	Active and veteran military personnel (Australia)	Military service requirements and operating environment.+1	27% experience regular urinary incontinence (23% UL, 16% urge).+2 LUTS are an ongoing problem for two-thirds of respondents; specific in-service monitoring is required.+1
Brock et al. (2024)	Quantitative Pilot Study	Adult women with a history of UI	Environmental and behavioral factors in the workplace.	Association between specific types of work/environments and increased incontinence and urgency. Identification of specific workplace behaviors related to symptom management.
Arguedas et al. (2023)	Basic Science Study	Women (Various sectors)	Job strain and bladder health.	Impact of high work demands and low job control on urinary health. Work-related stress is emerging as a determining factor in the chronicity of symptoms.+2
Markland et al. (2018) +1	Quick Review and Meta-analysis	Working women (Various groups)	Occupation as a risk factor for LUTS.+1	Correlation between specific occupational groups and the prevalence of urinary symptoms. Need for preventive interventions based on occupation type.

Author/year	Studio Design	Population/Sector	Ergonomic variables: physical, organizational, cognitive	Pelvic floor finding (LUTS/IO/Other)
Markland et al. (2023)	Cross-sectional Study (BACH Study)	Women (3,205 participants)	Workplace hygiene environment and occupational groups (SOC).	Significant variation in the prevalence of LUTS according to occupational group.+1 The physical environment of restrooms and access policies directly impact the severity of symptoms.+1
Gao et al. (2024) +2	Latent Class Analysis	Nurses (6,735 participants)	Organizational: Work-related stress and modifiable lifestyles.+3	Average of 2.2 symptoms per nurse; 4 distinct symptom profiles were identified.+2 Job stress is correlated with more severe and complex symptom profiles.+3
Carter Ramirez et al. (2022)	Longitudinal Cohort (10 years)	Perimenopausal women (USA/Canada)	Physical: Lifting and pushing heavy loads at work.	Frequent occupational lifting increases the risk of developing symptomatic pelvic organ prolapse (POP). The risk is cumulative and is heightened in women with a history of childbirth.
Addisu et al. (2023)	Systematic Review and Meta-analysis	Women (Ethiopia)	Physics: Carrying heavy objects and agriculture.	Prevalence of pelvic organ prolapse (POP) is 13.5%. Risk factors include heavy lifting and chronic constipation. There is a strong association between strenuous physical work and prolapse progression.
O'Shea et al. (2025)	Qualitative/Mixed Study	Military (Australia)	Physical: Carrying heavy equipment. Organizational: Military culture.	Significant prevalence of urinary incontinence (UI) and pelvic organ prolapse (POP) due to service demands. Women manipulate their menstrual cycles and avoid drinking water due to a lack of toilets.

Chow et al. (2022)	Cross-sectional study (LUTS Asia)	Women (China, Taiwan, Korea)	Limitations at work and the search for health.	Stress urinary incontinence (SUI) causes significant work limitations. Only a small percentage seek professional help due to stigma or normalization.
Gomes et al. (2020)	Cross-sectional study	Women (Brazil)	Work productivity and Overactive Bladder (OAB).	OAB symptoms are associated with lower productivity and higher absenteeism. Urgency symptoms have a greater impact on the quality of work life than frequency.
Kim & Kwak (2017)	Cross-sectional study	Working women (Korea)	Occupational status, type of employment and urinary incontinence (UI)	There is a higher risk of urinary incontinence (UI) in service and sales jobs compared to administrative jobs. Occupational status acts as a social determinant of pelvic health.

Author/year	Studio Design	Population/Sector	Ergonomic variables: physical, organizational, cognitive	Pelvic floor finding (LUTS/II/Other).
Lopes et al. (2019)	Systematic Review	Nurses (Brazil/Global)	Organizational: Long shifts. Physical: Patient mobilization.	High prevalence of urinary incontinence (up to 43%) and lower urinary tract infections (LUTS) among nursing staff. The behavior of postponing urination due to workload is the key factor.
Vesting et al. (2025)	Mixed Cohort (Quantitative + Qualitative)	Postpartum women (1st year)	Physical: Limitations in daily living and work activities after childbirth.	"Unknown body": weakness of the pelvic floor that limits physical exertion and return to work. +2
Porto et al. (2025)	Cross-sectional study (n=1,214)	Working women (Portugal)	Organizational: Impact on labor productivity (WP) and presenteeism.	The severity of urinary incontinence (UI) directly predicts lower productivity. +3
Gao et al. (2024)	Latent Class Analysis (LCA)	6,735 Nurses (China)	Psychosocial/Organizational: Work stress and urination behaviors.	It identifies 4 symptom profiles. High work stress is associated with the "Multiple Storage Symptoms" profile. +3
Pierce et al. (2017)	Cross-sectional study	2,024 Nurses/Midwives (Australia)	Organizational: Impact on staff retention and work environment.	Urinary incontinence (UI) is significantly associated with the intention to leave work. +3
Fransson et al. (2024)	Retrospective Descriptive	Veterans and Civilians (Canada)	Physical/Clinical: Military background and chronic pain.	High frequency of pelvic floor symptoms in women with chronic pain; higher prevalence of stress urinary incontinence in veterans.
Salo et al. (2024)	Cohort Study	2,757 Women (Finland)	Physical/Organizational: Self-perceived work capacity (Work Ability Index).	Urgent incontinence (especially emergency and mixed incontinence) significantly reduces physical and mental capacity for work.

Note: Adapted from publications reported by PubMed, ScienceDirect, Scopus, and Taylor & Francis.

5. CONCLUSIONS

It is concluded that traditional ergonomics models have historically ignored the biomechanical specificity of the abdominal lumbopelvic-peroneal complex. While physical ergonomics focuses on back or limb injuries, this review demonstrates that the pelvic floor is a critical support structure that suffers chronic fatigue from load handling and prolonged standing, especially in operational and military sectors.

The phenomenon of "occupational bladder" as an organizational failure: evidence indicates that organizational ergonomics is the most malleable yet least addressed determinant. Dysfunctions arise not only from female biology but also

from rigid work structures that force women to "postpone urination" or restrict hydration to meet production targets or due to a lack of relief workers. This transforms a natural physiological process into an occupational risk.

A critical impact on productivity has been identified: pelvic floor dysfunction (PFD) has a direct impact on companies' bottom line. Beyond sick leave, presenteeism (being at work despite pain, discomfort, or distraction due to urinary symptoms) reduces cognitive capacity and expert performance. Therefore, investing in pelvic health is not a healthcare expense, but rather a strategy for productivity and talent retention.

The review highlights a critical gap in the return to work after childbirth. There is a conflict between physiological recovery and pre-existing ergonomic demands. Women often face an "unfamiliar body" that no longer responds in the same way to physical exertion, suggesting the need for specific ergonomic transition protocols for working women after maternity leave.

There is a clear inequity in the distribution of risk: women in operational and service roles have a higher prevalence of symptoms than those in managerial positions. This indicates that socioeconomic level and type of contract directly influence a woman's ability to manage her pelvic health during the working day.

CONTRIBUTIONS TO ERGONOMICS

The most significant contribution of this review is its strengthening of the ergonomic approach with a gender perspective, focusing on a topic that is underexplored and underrecognized in the workplace: the health of the female pelvic floor. It reinforces occupational ergonomics by integrating a gender perspective that transcends the traditional biomechanical view, positioning the health of the female pelvic floor as a critical indicator of the interaction between the worker and her work system. By highlighting conditions such as incontinence and prolapse within the productive environment, the research redefines the concept of physical workload, incorporating intra-abdominal pressure and pelvic support fatigue. Furthermore, it elevates the relevance of organizational ergonomics, demonstrating that time management and access to hydration and urination are not merely wellness issues, but essential administrative controls for preventing "occupational bladder" and presenteeism.

Ultimately, this scientific contribution provides ergonomics with a longitudinal and dynamic perspective, recognizing the physiological particularities of returning to work after childbirth and during aging, thus enabling the design of workplaces that ensure the sustainability of women's health and the economic efficiency of organizations. This review significantly contributes to the scope of the scientific literature on pelvic floor dysfunction from an ergonomic perspective.

AI Statement

The authors declare the use of Gemini's generative AI to support the collection of preliminary information from certain passages of the text in order to obtain specific data on the variables of interest. The material was reviewed to ensure the accuracy of the content, and the originality of the authors' ideas is guaranteed in compliance with ethical codes.

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5S APPLICATION AND ERGONOMIC PROPOSAL FOR A SEWING WORKSHOP

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Resumen: Este artículo presenta un caso de estudio sobre un taller de costura, en el que se analizan las condiciones de trabajo que afectan negativamente la salud física de los trabajadores. Se identificaron problemas como posturas forzadas, espacios reducidos y máquinas inadecuadas, que representan riesgos para la salud musculoesquelética. El objetivo principal es analizar los riesgos asociados a las tareas de costura y desarrollar una propuesta de rediseño de la distribución del lugar de trabajo, mediante el análisis detallado de las actividades y la aplicación de principios ergonómicos y antropométricos. A través de un análisis exhaustivo, se detectaron molestias musculoesqueléticas en los trabajadores. Se utilizó la videograbación con GOMPLAYER ©, en su versión gratuita para estudiantes, lo que nos ayudó a identificar posturas estresantes y frecuentes durante las tareas. Con base en los resultados, se aplicaron principios antropométricos para sugerir modificaciones en el diseño de las estaciones de trabajo. Además, se utilizó el método RULA (Rapid Upper Limb Assessment) para evaluar el riesgo de lesiones musculoesqueléticas e identificar las principales áreas de riesgo ergonómico. Las zonas del cuerpo más afectadas fueron las manos, las muñecas, la espalda y el cuello. En el análisis del trabajo, se evaluaron cinco posturas, de las cuales dos presentaron riesgo según el método RULA. El estudio también detectó deficiencias en el diseño ergonómico, como la ausencia de soporte lumbar, la altura inadecuada de las mesas y una distribución ineficiente del mobiliario, factores que contribuyen al malestar físico de los trabajadores. La propuesta de intervención se basa en el rediseño integral del área de trabajo, incorporando los principios antropométricos y los resultados del análisis RULA. Se sugiere reubicar los elementos del taller para optimizar las zonas de alcance y ajustar la disposición de los muebles. Además, se propone incorporar una nueva máquina que elimine el impacto del pedal sobre las trabajadoras, lo que contribuirá a reducir las molestias físicas, mejorar la comodidad y aumentar la eficiencia laboral. Para complementar estas mejoras, se recomienda implementar el sistema de organización 5S (clasificación, orden, limpieza, estandarización y disciplina), con el fin de mejorar la organización, la limpieza y el mantenimiento del área de trabajo. Esta metodología contribuirá a optimizar el entorno laboral, promoviendo un espacio más seguro, eficiente y agradable para los

trabajadores. En conclusión, los cambios propuestos no solo buscan mejorar las condiciones ergonómicas del taller de costura, sino también generar beneficios sostenibles a largo plazo, tanto en salud laboral como en eficiencia operativa.

Palabras clave: Ergonomía, Postura, Riesgo, RULA, Estación de trabajo

Relevancia para la ergonomía: Este artículo muestra cómo el diseño inadecuado en un taller de costura afecta la salud de los trabajadores y cómo el análisis ergonómico puede generar mejoras prácticas. La ergonomía y la postura son aspectos clave, ya que se identifican posiciones dañinas y se sugieren correcciones. La evaluación del riesgo y el uso del método RULA aportan datos objetivos sobre el esfuerzo musculoesquelético. El rediseño de la estación de trabajo con base en principios antropométricos ofrece soluciones replicables. Su publicación es valiosa para fomentar entornos laborales más seguros y eficientes, especialmente en industrias pequeñas

Abstract: This article presents a case study of a sewing workshop, in which the working conditions that negatively affect workers' physical health are analyzed. Issues such as forced postures, limited space, and inadequate machines were identified, all of which pose musculoskeletal health risks. The main objective is to analyze the risks associated with sewing tasks and develop a proposal to redesign the workspace layout through detailed task analysis and the application of ergonomic and anthropometric principles. Through a thorough analysis, musculoskeletal discomfort was detected among the workers, and video recordings using GOMPLAYER© (a free version for students) helped identify stressful and frequent postures during the tasks. Based on the results, anthropometric principles were applied to suggest modifications to the workstation design. In addition, the RULA (Rapid Upper Limb Assessment) method was used to assess the risk of musculoskeletal injuries and to identify the main ergonomic risk factors. The most affected body parts were the hands, wrists, back, and neck. In the work analysis, five postures were evaluated, of which two were classified as high risk according to the RULA method. The study also identified ergonomic design deficiencies, including a lack of lumbar support, inappropriate table height, and inefficient furniture layout—factors that contribute to workers' physical discomfort. The proposed intervention focuses on a comprehensive redesign of the workspace, incorporating anthropometric principles, and the results obtained from the RULA analysis. It suggests repositioning elements within the workshop to optimize reach zones and adjusting the furniture arrangement. Additionally, a new machine is proposed to eliminate the negative impact of the pedal on the workers, aiming to reduce physical discomfort, improve comfort, and increase work efficiency. To complement these improvements, implementing the 5S organizational system (Sort, Set in order, Shine, Standardize, Sustain) is recommended to enhance workspace organization, cleanliness, and maintenance. This methodology will help optimize the work environment, promoting a safer, more efficient, and more pleasant space for workers. In conclusion, the proposed changes aim not only to improve the ergonomic conditions of the sewing workshop but also to generate long-term, sustainable benefits for both worker health and operational efficiency.

Keywords: Ergonomics, Posture, Risk, RULA, Workstation

Relevance to Ergonomics: This article highlights how poor workplace design in a sewing workshop affects workers' health and how ergonomic analysis can lead to practical improvements. Ergonomics and Posture are central, as the study identifies harmful positions and proposes corrective actions. The assessment of Risk and use of the RULA method provides objective data on musculoskeletal strain. Redesigning the Workstation based on anthropometric principles offers replicable solutions. Its publication is valuable for promoting safer, more efficient work environments, especially in small-scale industries.

1. INTRODUCTION

This study was conducted in a small-scale sewing workshop, where the work environment and production processes were analyzed to identify factors that could compromise workers' physical health. Stressful postures prone to causing musculoskeletal injuries, inefficient spatial layout, recurrent muscle discomfort among staff, and highly repetitive tasks were identified. Ergonomics is essential for designing safer, more efficient work environments, while anthropometry enables analysis of body measurements needed to achieve optimal biomechanical adjustments. The primary objectives include identifying ergonomically correct postures during operations, redesigning the workspace layout to foster a more functional, effective, and safe environment, and quantifying the physical impact of tasks performed.

The 5S Methodology is a system aimed at organizing and maintaining clean workspaces, thereby improving productivity and product quality.

It originated in Japan in the 1950s as part of the Lean Manufacturing production system, intending to promote efficiency and organization in the workplace.

- **Seiri (Sort):** This step involves distinguishing between necessary and unnecessary items and eliminating the non-essential ones. The purpose is to reduce clutter and free up workspace, making it easier and faster to locate the tools and materials needed to perform tasks.
- **Seiton (Set in Order):** This step focuses on arranging and organizing the workspace. Essential items are systematically placed to allow quick access, thereby minimizing search time and reducing the risk of errors.
- **Seiso (Shine):** The goal is to encourage cleanliness and keep the workplace clean at all times, creating a safer and more pleasant environment. Regular cleaning also helps identify potential problems or defects in equipment or infrastructure.
- **Seiketsu (Standardize):** This phase involves establishing rules and procedures to maintain the first three S's consistently. It facilitates staff training and ensures continuity in implementing the method.

- **Shitsuke (Sustain):** This final stage promotes discipline and self-responsibility. It aims to ensure that employees follow established rules and consistently apply the previous four S's, embedding efficiency and continuous improvement into the organization's culture.

Based on the results of Gómez Fretes's (2023) study, the implementation of the 5S methodology significantly improves organization, control, and the standardization of activities within the textile production area. The application of this continuous improvement tool allows for better distribution and management of materials and tools, while also promoting order and cleanliness in the workplace. In this sense, the findings indicate that adopting the 5S methodology is an effective strategy for strengthening production management and improving working conditions in the textile sector.

Similarly, the results presented in the article by Quispe et al. (2022) were highly useful for developing this study. The authors describe the implementation of the 5S methodology in textile companies, highlighting proposals such as reorganizing work areas to improve the arrangement of materials and tools. This approach is particularly relevant to the present project, as similar issues were identified in the sewing workshop analyzed, including disordered workspaces, materials placed outside their designated locations, and inconsistent cleaning practices. These problems occur frequently in the small workshop, affecting organization and efficiency in daily operations.

1.2 Problem statement

Small businesses face intense competition within their sector, leading them to prioritize speed over addressing potential future risks or challenges. They often lack the information needed to implement controlled, safe processes. Additional challenges include limited resources, poor spatial or role distribution, understaffing, and shortages of essential equipment.

In sewing workshops, the primary issues stem from inadequate workspace design. These spaces are often cramped and poorly organized, despite the need for ample and well-distributed areas to accommodate large machinery. Observations within the workshop revealed specific process-related problems:

- **Hand and Wrist Stress:** Sewing requires continuous manipulation of garments with the hands and repetitive wrist movements throughout the workday, leading to strain and pain in these areas.
- **Stressful Postures:** Certain processes involve improper postures that cause discomfort or may result in musculoskeletal injuries. For example, during cutting and sewing operations, workers adopt strained postures and experience mechanical stress.
- **Poor Lighting:** Insufficient lighting increases the risk of accidents during cutting, sewing, or movement within the workspace. It also causes eye strain during tasks.
- **Mechanical Stress:** Handling scissors generates mechanical stress on the palms and sides of the fingers.

The tasks performed in the business are:

- Cutting and Garment Design: This process involves creating the pattern for each piece and cutting the necessary fabric. It is performed at a worktable while standing.
- Organizing Pieces: In this step, each garment piece is sorted and prepared for sewing.
- Straight Stitch Sewing: This is the most time-consuming process, as it includes all tasks required to assemble the garment. It is performed in a seated position.
- Cutting Elastic or Extra Pieces: Elastic or additional materials needed for the garment are cut at a worktable in a standing position.
- Folding and Arranging: Once the garment is assembled, it is folded and packed into small bundles for delivery. This is done at a worktable while standing.
- Area Cleanup: At the end of the workday, the workspace is swept, and tools are organized.

It is important to note that the workshop collaborates with various companies, and some processes may be modified or omitted depending on client requirements. For example, the cutting and design phase may be skipped for certain projects.

Detected shortcomings of the current design

Due to understaffing, workers perform multiple tasks during their shifts.

- Poorly Distributed Areas: Machines are placed with inadequate spacing, leaving each machine in a cramped workspace.
- Clutter in the Workspace: Poor organization leads to unnecessary materials occupying valuable space and misplaced items that hinder efficient workflow.
- Lack of Support Surfaces: There is no designated table for materials or tools. Workers store tools and garments together at the base of the machines, causing obstructions during garment handling and occasional tool drops.

Workplace risk factors detected

- One of the machines features a lever that requires knee force to lift the presser foot and insert the garment. Since the body comes into contact with a hard, sharp structure, this can cause knee discomfort and even minor bruising.
- During the cutting and design process, the table height is unsuitable for workers. The table is too low, leading to stress on the back and discomfort.
- In the sewing process, workers sit in stressful postures on chairs unsuitable for the job. Given that workers vary in body measurements, the chair height cannot be adjusted to fit everyone, resulting in poor ergonomic alignment. Additionally, the wooden chairs lack padded backrests and seats, causing back and thigh discomfort during long work shifts.

1.2.2 Justification

Reduction of fatigue and musculoskeletal discomfort: Adjusting worktables and chairs will help maintain proper posture, reducing tiredness and pain in muscles and joints. This will allow workers to feel more comfortable and perform their tasks for longer periods without discomfort.

Increased efficiency and productivity in garment manufacturing: An ergonomic work environment reduces fatigue and enhances comfort, leading to greater concentration and speed in tasks. Production efficiency will improve, resulting in more garments being produced in less time and of higher quality.

1.2.3 Delimitations

This study will focus exclusively on the ergonomic working conditions within the sewing workshop, considering factors such as posture, lighting, furniture design, and physical exertion. The sewing workshop has two types of industrial machines: ZOJE-branded. The first model is a straight-stitch machine, and the second is an overlock. In our case, we will focus on the straight-stitch machine.

2. OBJECTIVES

The general objective of this proposal is to apply ergonomic and anthropometric principles to the analysis of the work environment in the sewing workshop, and to propose ergonomic improvements that reduce risks and enhance work efficiency.

2.1 Specific Objectives

1. Identify the main ergonomic risks in the workshop through observations and analysis methods such as the Body Map. (Marley y Kumar, 1996)
2. Develop a proposal based on anthropometric and ergonomic principles tailored to the selected area and the workers.
3. Design and propose improvements to the workspace layout, lighting, and furniture to reduce the physical exertion of the workers.

3. METHODOLOGY

This study was conducted in a sewing workshop where two women, aged 35 and 45, work. They have been working for 5 to 10 years and work 8-hour days.

3.1 Stage 1. Analysis of musculoskeletal complaints.

This method involves a general assessment of musculoskeletal discomfort experienced by workers at their workstations. The method developed by Marly and

Kumar (1996) is based on workers' assessments of both the frequency and intensity of discomfort, guided by a body map.

On the body map, the worker will identify body parts and assign a value from 0 to 3 to indicate the frequency of discomfort, where 0 indicates no discomfort and 3 indicates high frequency of discomfort. Likewise, the level of discomfort will be identified from 0 to 10, where 0 indicates no discomfort and 10 indicates extreme discomfort.

Once the information was collected, the Action Levels were identified, represented by a color chart that categorizes the urgency of corrective measures. The green zone indicates that intervention is not necessary; the yellow zone indicates the likelihood that intervention will be required; and the red zone indicates the need for intervention.

We graphed our results to understand them better. With this method, we were able to identify the most affected areas of the body.

3.2 Stage 2. Analysis of the work and application of anthropometry.

The work analysis was conducted using video recordings and GOMPLAYER software (GOM Player application®), which allowed us to analyze in detail all the workers' postures during the process and identify stressful postures and the frequency with which these activities are performed within the sewing workshop.

Once the postures were identified, we used anthropometric data as a reference to assess whether the worktables, machines, and tools fit the workers' body dimensions.

Data from Table VIA-2: Anthropometric Data, Centimeters (Adapted from P. C. Champney, 1979, and B. Muller-Borer, 1981, Eastman Kodak Company; NASA, 1978). It was considered because they provide us with data on body measurements, which allows us to design adjustments to meet the needs of the population, and it can also guarantee that the spaces or tools are compatible with most of the population. North American tables are also a standardized and accepted tool, facilitating understanding for designers, engineers, etc.

Based on the information obtained to date, we determined the most relevant measures for designing our spaces, as well as the percentiles we will use when redesigning our workstations.

3.3 Stage 3. Evaluation using the RULA Method (Rapid Upper Limb Assessment)

For the ergonomic analysis of postures adopted by workers during their activities, the Rapid Upper Limb Assessment (RULA) method, developed by McAtamney and Corlett in 1993, was used to assess workers' exposure to risk factors that contribute to high postural loads and may lead to upper limb disorders. It evaluates individual postures rather than sequences or combinations of postures. Therefore, it is necessary to select specific postures that the worker adopts during evaluation tasks. The method is divided into two groups:

Group A: Evaluates the arm, forearm, and wrist.

Group B: Evaluates the neck, trunk, and legs.

Each group includes a scoring table. By assigning scores based on observed postures, the intersecting value in the table determines the group score. Group A then becomes Group C, and Group B becomes Group D. A final assessment considers activity frequency and applied force or load. The scores from Groups C and D are cross-referenced in the Action Level Table to determine whether task redesign is necessary or if the current setup is acceptable. This method was selected for its ease of use and effectiveness in identifying postural risks associated with musculoskeletal disorders of the neck, trunk, and upper extremities.

RULA (McAtamney and Corlett, 1993) was applied through direct observation of workers while they performed their activities. The postures of the neck, trunk, arms, and wrists were recorded, as well as the perceived muscle load and force exerted. Based on these data, scores were assigned according to the RULA method table, which classified the risk level on a scale of 1 to 7, with higher scores indicating a more urgent need for ergonomic intervention.

The data obtained were used to identify high-risk postures and propose recommendations for improvement. We completed the analysis with photographic records of the analyzed postures.

3.4 Stage 4. Proposed workstation improvements.

Once the space was analyzed and we identified the musculoskeletal discomforts that needed to be addressed, the anthropometric applications we should consider, and the postures that posed a risk, we developed an improvement proposal consisting of redesigning the space.

For this redesign, we considered the most relevant body dimensions based on anthropometric tables and their percentiles. We also considered the anthropometric principle of designing for adjustability.

The goal is to reduce risk factors and musculoskeletal discomforts, or, ideally, eliminate them.

4. RESULTS

4.1 Results of the musculoskeletal Discomfort analysis

The results of the analysis of musculoskeletal complaints with the Marley and Kumar (1996) Body Map are presented below.



Figure 1. Analysis of the Marley and Kumar (1996) Body Map

According to the graph, the most affected body parts for both workers are the left hand, glutes, and right leg. We also see that the greatest discomfort is in the upper and lower back.

4.2. Analysis of the Work and Application of Anthropometry

As part of the ergonomic study conducted in the sewing workshop, a discomfort analysis was conducted to identify the body areas experiencing the greatest discomfort during the workday. A color-coded bar chart was used to highlight the priority areas for attention visually.

The colors represent different levels of discomfort:

● **Green Zone:** Refers to body parts with minimal or no discomfort. These areas do not pose an immediate ergonomic risk but should be monitored to prevent long-term deterioration.

● **Yellow Zone:** Indicates moderate discomfort. These areas could develop into more serious problems if posture, tools, or exposure time are not adjusted. They represent a medium ergonomic risk.

● **Red Zone:** Highlights areas with intense or constant discomfort. These zones require immediate attention, as the risk of developing musculoskeletal injuries is high. In the workshop, the most affected areas were the lower back, upper back, glutes, and hands, which are associated with prolonged postures, repetitive manual work, and inadequate support.

This analysis helps prioritize specific ergonomic interventions such as furniture adaptation, workspace redesign, active breaks, and the use of postural supports.

Implementing these measures will not only prevent injuries but also improve the well-being and productivity of the workers.

4.2.1 Analysis of the work

To carry out this analysis, it was essential to evaluate each task, identify potential ergonomic risks, and propose strategies to optimize efficiency, comfort, and worker safety. Below is a comprehensive analysis covering the process from material cutting to assembly for creating a trouser piece.

Description of Tasks and Postures in the Sewing Workshop

- **Material Cutting:** This fundamental process begins with material selection, followed by precise measurement using tools such as rulers, measuring tapes, and cutting patterns to ensure each piece meets required dimensions. Finally, the material is cut with scissors.
- **Back View:** At this stage, the worker performs cutting or sewing tasks while being observed from a rear perspective. This position allows for a detailed analysis of posture and movements, using frame-by-frame analysis to identify potential ergonomic risks. Through this method, factors such as improper posture, repetitive strain, or movements that could cause muscle tension can be detected, contributing to the implementation of preventive measures to enhance worker safety and well-being.
- **Pedals:** During the sewing process, the worker uses the sewing machine pedals to control its operation. However, it has been observed that in some positions, the knee comes into direct contact with the pedal, leading to an uncomfortable posture and increased joint strain. This repetitive effort can lead to muscle fatigue and ergonomic risks. *revisar el texto*
- **Use of sewing machines:** During the sewing process, the worker operates the machine with a pedal to control its operation. However, it has been observed that, in some positions, operating the machine activates a lever, which comes into direct contact with the leg, causing an uncomfortable posture and increased joint strain. This repetitive effort can lead to muscle fatigue and potential ergonomic risks.
- **Attaching Strips to the Trouser Piece:** Once the material is cut, the process of attaching strips to the trouser pieces begins. At this stage, the worker sits in front of the sewing machine, ensuring proper alignment and fixation of each strip. It is important to monitor their posture and movements, as repetitive gestures and prolonged positioning can lead to muscle tension.
- **Assembling the Trouser Piece:** In this final stage of the process, all previously prepared pieces are joined to shape the trouser piece. The worker remains seated at the sewing machine, ensuring each component is securely fixed and properly aligned.

Frame analysis using the GOM Player application ®. The following results were obtained from the analysis of 100 random frames:

Table 2 Job Analysis

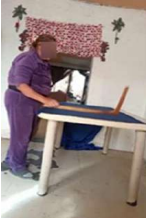
Photo frame	Numbers of photo frame	Frequenc y	% of frequency	Cumulativ e frequency
Cutting material 	111,12,15,16,18,21,27,28,30,31,35,36	12%	12%	12%
Back 	116,117, 118, 120, 121, 124, 125, 126, 127, 128, 129, 131, 132, 155, 156, 161, 162, 164, 165, 168, 170, 172	22%	22%	34%
Pedals 	6, 7, 174, 177, 179, 181, 182, 183, 185, 186, 188, 189, 191, 192, 196, 197, 198	17%	17%	51%
Attaching the trousers strip 	99, 101, 103, 105, 108, 113, 114, 135, 137, 138	10%	10%	61%
Joining the trousers pieces 	3, 4, 41, 44, 45, 46, 48, 49, 50, 52, 53, 55, 57, 58, 59, 60, 63, 64, 65, 69, 71, 73, 78, 79, 80, 84, 85, 86, 87, 88, 92, 95, 96, 97, 141, 143, 144, 149, 154	39%	39%	100%

Figure 2. Examples of some photo frames captured by the GOM PLAYER application

4.2.1.1. Identification of ergonomic risks encountered

Uncomfortable postures: Sewing activities can lead to uncomfortable postures, as workers spend long periods sitting and leaning forward due to the lack of worktables at the appropriate height. This situation causes pain in the upper and lower back.

Repetitive movements: Cutting, measuring, and gluing the pieces of the pants involve repetitive wrist and hand movements, leading to muscle fatigue.

4.2.1.2. Definition of relevant body dimensions for design

For injury prevention, using appropriate dimensions and percentiles is crucial. Percentiles are used to represent variations in people's body dimensions and ensure that furniture, equipment, and space designs accommodate a wide range of users. The 5th and 95th percentiles of female height were utilized.

In the sewing process, we calculated the following dimensions:

1. Sitting eye height: This is one of the critical dimensions, as it refers to the vertical distance from the seat to the worker's eyes.

Sitting eye height:

$$x = 73.7 \quad S.D = 3.1$$

$$X = 73.7 + 3.1(-1.65)$$

$$X = 68.585 \text{ CM}$$

5 percentil

2. Sitting knee height (popliteal height): This dimension is indispensable because it allows us to assess the necessary chair height adjustment to avoid discomfort or incorrect postures. It is measured from the floor to the back of the knee (popliteal fossa).

Sitting, knee height (popliteal height)

$$x = 51 \quad S.D = 26$$

$$X = 51 + 26(-1.65)$$

$$X = 46.71 \text{ CM}$$

5 percentil

3. Standard seat height: This dimension evaluates the distance from the floor to the top of the seat.

$$\bar{x} = 81.8 \quad S.D = 4$$

$$X = 81.8 + 4(1.65)$$

$$X = 88.4 \text{ CM}$$

95 percentil

$$\bar{x} = 81.8 \quad S.D = 4$$

$$X = 81.8 + 4(-1.65)$$

$$X = 72.2 \text{ CM}$$

5 percentil

4- Elbow to fist length - is the distance from the elbow (on the inside of the elbow, at the crease) to the fist (the end of the hand, where the fingers join).

$$\bar{x} = 34.8 \quad S.D = 2.3$$

$$X = 34.8 + 2.3(-1.65)$$

$$X = 31.005 \quad \text{CM}$$

5 percentil

5- Buttock-to-popliteal length: This measurement is taken from the most prominent part of the buttocks (typically the back of the hip) to the back of the knee. This dimension is essential for chair adjustments

Buttock-to-popliteal length

$$\bar{x} = 48 \quad S.D = 3.2$$

$$X = 48 + 3.2(-1.65)$$

$$X = 42.72 \quad \text{CM}$$

5 percentil

6-Seated shoulder width: This measurement is taken from one shoulder to the other when a person is seated.

Seated shoulder width

$$\bar{x} = 39 \quad S.D = 2.1$$

$$X = 3 + 2.1(1.65)$$

$$X = 42.465 \quad \text{CM}$$

95 percentil

7-Hip breadth - This measurement is taken at the widest part of the hips.

Hip breadth

$$\bar{x} = 38 \quad S.D = 2.6$$

$$X = 38 + 2.6(1.65)$$

$$X = 42.29 \quad \text{CM}$$

95 percentil

8-In the cutting process, the following dimensions were calculated:

Standing eye height: This dimension is measured from the floor to the eyes when the worker is in an upright and natural position.

Standing eye height

$$\bar{x} = 151.4 \quad S.D = 5.6$$

$$X = 151.4 + 5.6(-1.65)$$

$$X = 142.16 \quad \text{CM}$$

5 percentil

These are images of the current design of the work area. We can observe that the chair measurements are inadequate; they are not adjustable for each worker, and the backrest and seat are hard surfaces. We have measurements of the machine that show the lever mentioned earlier, which causes knee discomfort. We can also observe that no additional table has been implemented to place the materials or tools used during sewing, leading to poor organization, obstruction

during sewing, and even tools falling. The machine's base is too small to accommodate the garment, hold material, and keep tools in the same place.

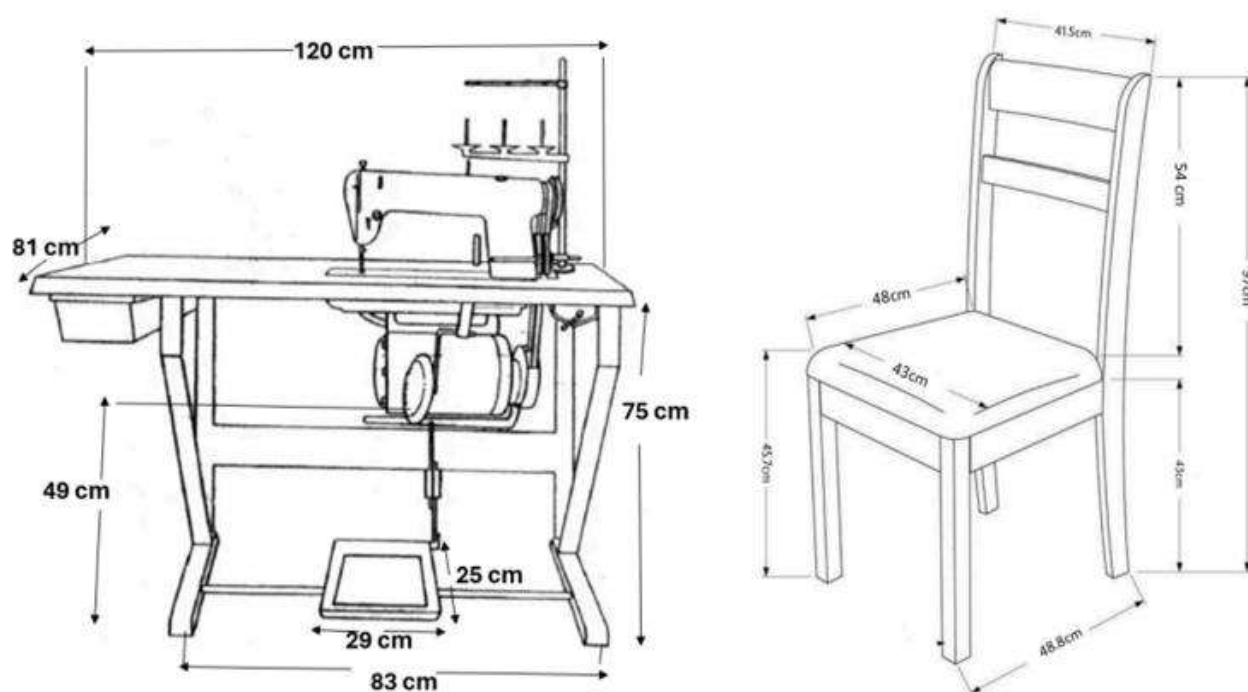


Figure 3. Workstation Dimensions (sewing machine and chair) 1

We have the worktable with a height of 77 cm, which we can observe is inadequate. Considering that the workers have varying body dimensions, an adjustable height is required for each worker.

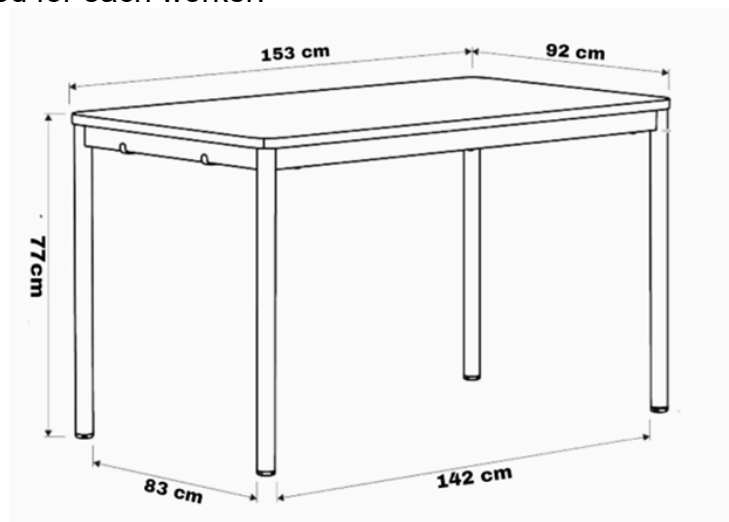


Figure 4. Workstation Dimensions (Table) 2

3.4 Evaluation with the RULA Method (Rapid Upper Limb Assessment)

For this study, the RULA method was applied because most processes involved awkward postures that pose potential injury risks.



Figure 5. Posture 1

In the first task, we can observe that the back is not straight; it is hunched due to the table's height. This is the garment cutting and design process.

- Through the evaluation of Group A, we observe that the arm is in a flexion range of 45 to 90 degrees, and the arm is abducted. We can see that the forearm has a flexion between 60 and 100 degrees. The wrists have a flexion greater than 0° and less than 15°, with no radial or ulnar deviation. The wrist is in a mid-range twist. This results in a Group A score of 4.
- In Group B, we observe that there is neck flexion greater than 10° and less than 20°, with no lateral tilt or head rotation. The trunk has a flexion of 0° to 20°, with no rotation or lateral tilt. The worker is standing with symmetrically distributed weight and space to change positions, resulting in a Group B score of 5. Through the load or force assessment, we observe that the ruler is being carried, which is assigned a score of 0 (load less than 2 kg). However, the activity is highly repetitive (more than 4 times per minute), adding 1 point to each group.
- With an Action Level of 3, requires task redesign



Figure 6. Posture 2



Figure 7. Posture 2



Figure 8. Posture 2

In the following image, we observe the sewing process, with three views of the same task: a side view, a back view, and a view of the leg and knee.

- The calculations performed yielded an action level of 4, requiring urgent changes to the task



Figure 9. Posture 5

In this process, pieces of clothing are joined to the trouser frame. In this task, we can observe a stressful posture. The back has a forward tilt, causing discomfort and unease.

- The calculations performed yielded an action level of 2, which indicates that changes may be required, but further study is needed.

position	CLUSTER A							
	score				Score Table A	Muscle use	force Load	addition
position 1	Arm Lift	Location of the	Wrist Position	Twisted Writ				
	2	1	2	2	4	1	0	5
	CLUSTER B							final score
	neck analysis	trunk position	leg balance	Score Table B	Muscle use	force Load	addition	level 3 requires task redesign
position 2	3	2	1	3	1	0	4	
	CLUSTER A							final score
	Arm Lift	Location of the	Wrist Position	Twisted Writ	Score Table A	Muscle use	force Load	addition
	3	2	3	1	4	1	0	5
Position 3	CLUSTER B							final score
	neck analysis	trunk position	leg balance	Score Table B	Muscle use	force Load	addition	Level 4 requires urgent changes to the task
	4	3	1	6	1	0	7	
	CLUSTER A							final score
Position 3	Arm Lift	Location of the	Wrist Position	Twisted Writ	Score Table A	Muscle use	force Load	addition
	3	1	3	1	4	1	0	5
	CLUSTER B							final score
	neck analysis	trunk position	leg balance	Score Table B	Muscle use	force Load	addition	level 2 changes to the task may be requiered, but further study is nesesity and advisable
Position 3	2	2	1	2	1	0	3	

3.4 Improvement Proposal and Recommendations

Description of the Work Environment

The sewing workshop is a small space where workers are engaged in making, adjusting, and repairing garments. It includes a central worktable, a sewing machine, a fabric storage area, and tools such as scissors, rulers, pins, and measuring tape. The current layout forces workers to maintain prolonged seated postures, often leaning forward or making repetitive movements with the right arm and leg due to the foot-operated lever system on the sewing machine.

Through ergonomic analysis, we identified several issues:

- Inadequate chair: The current chair is rigid, non-adjustable, has an uncomfortable backrest, and lacks wheels. As indicated by the RULA method analysis, workers are exposed to stressful postures.
- Potential associated injuries: Chronic lower back pain, sciatic nerve compression, poor blood circulation in the lower limbs.
- Worktable: Based on measurements taken of eye and knee height while standing, the current worktable does not meet ergonomic height standards for the workers.
- Potential associated injuries: Dorsal and cervical back pain, shoulder muscle strain, musculoskeletal disorders due to forward leaning.
- Sewing machine: As previously mentioned, the knee-operated lever causes discomfort and increases the risk of injury.
- Potential associated injuries: Repetitive mechanical stress injuries, right knee injury.
- Work area layout: Poor material organization was detected, leading to obstructions, unnecessary movements, and decreased efficiency.

- Potential associated injuries: Muscle fatigue from trunk twisting, wrist and shoulder pain due to repeated stretching.

Based on anthropometric analysis and workplace observations, solutions were proposed that focused on redesigning furniture, incorporating more functional technology, and reorganizing the workspace. These proposals stem from both direct observation and the anthropometric study conducted.

Proposed improvements:

- **Chair replacement:** Replace the current chair with an ergonomic model featuring adjustable height, a wide backrest, and wheels to facilitate mobility, as shown in the following image.

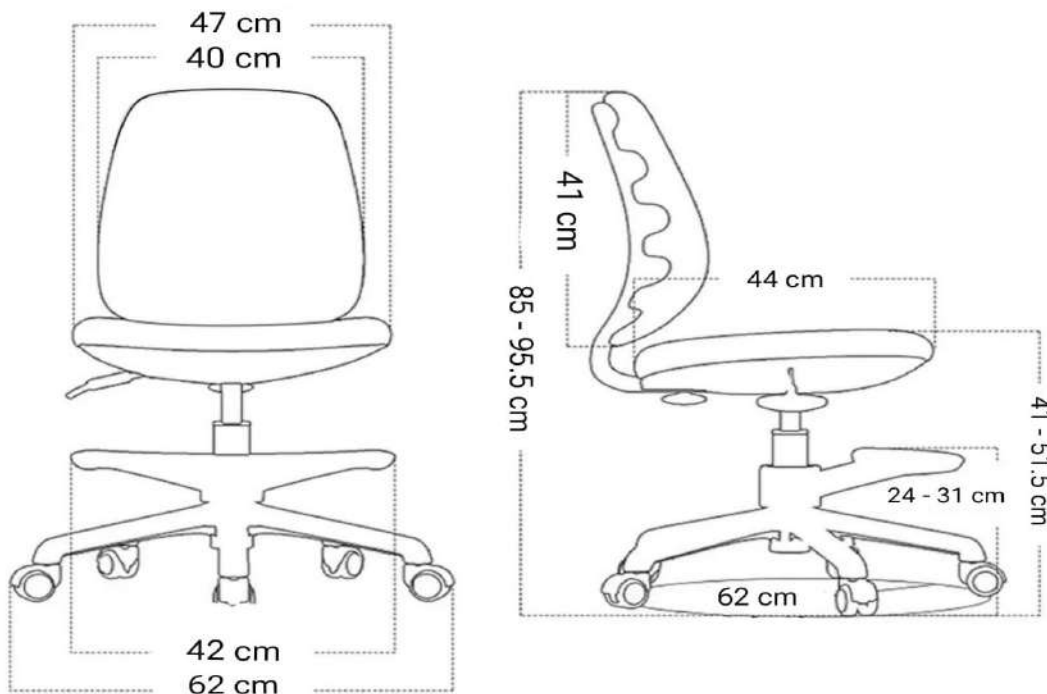


Figure 10. Dimensions of the new chair

This chair improvement is based on the recommendation that workers perform their tasks while seated, as this facilitates their work. According to the analysis, the most appropriate working position is seated. Making these modifications to the chair is crucial, since workers spend most of their workday using it, and this change could significantly improve their posture and overall comfort.

- **Adjustable worktable:** Incorporate a table with adjustable height and an additional lower compartment for material storage. This will allow better adaptation to workers' needs, reduce space usage, and improve access to materials and tools. The proposed table includes the following dimensions and also features the option to expand or reduce its size depending on space requirements.

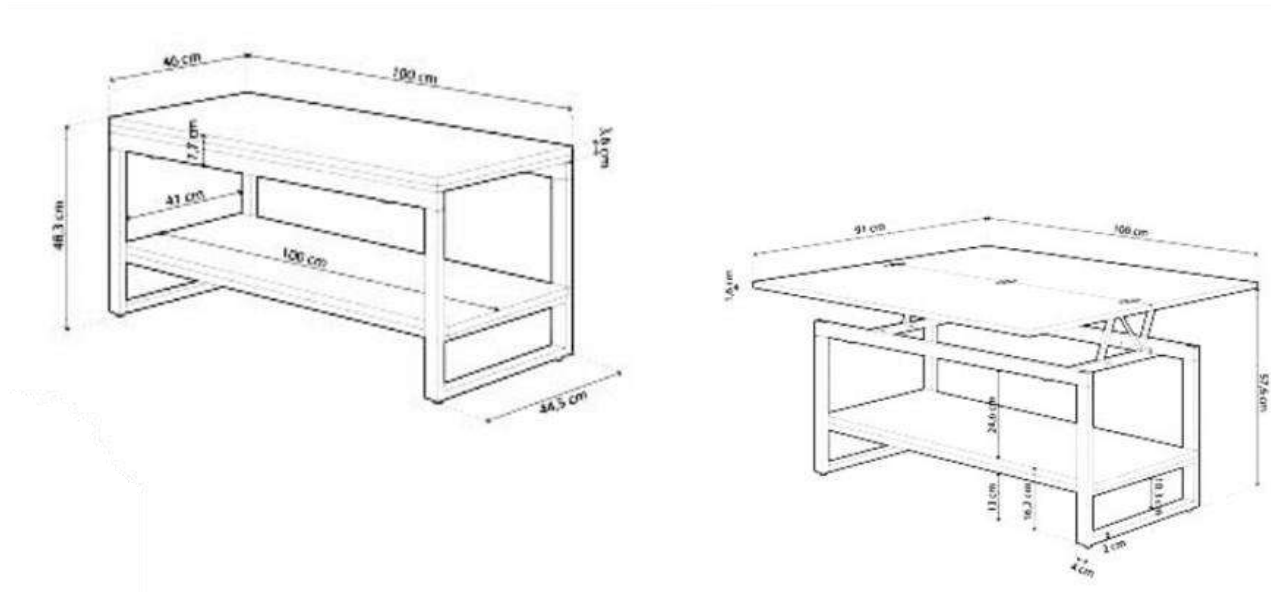


Figure 11. Dimensions of the new cutting table

Making this change to the table will improve posture, as the task is performed while standing. The ability to adjust both the table's height and width provides greater comfort for workers.

Proposed Table (Figure 11):

- Adjustable height: From 70 cm to 100 cm
- Additional compartment: Lower storage for tools and materials
- Expandable width: Allows adaptation to available space

Highlighted

- Enhances standing posture during cutting activities
- Reduces forward bending and awkward postures
- Increases comfort and accessibility
- Promotes better vertical reach (optimal range: 70–120 cm)

Improvements:

- **Sewing machine replacement:** Based on the analysis of the current machine, it is recommended to replace it with a more modern model that includes an automatic system, eliminating the need for the lever mechanism, as shown in the following image.

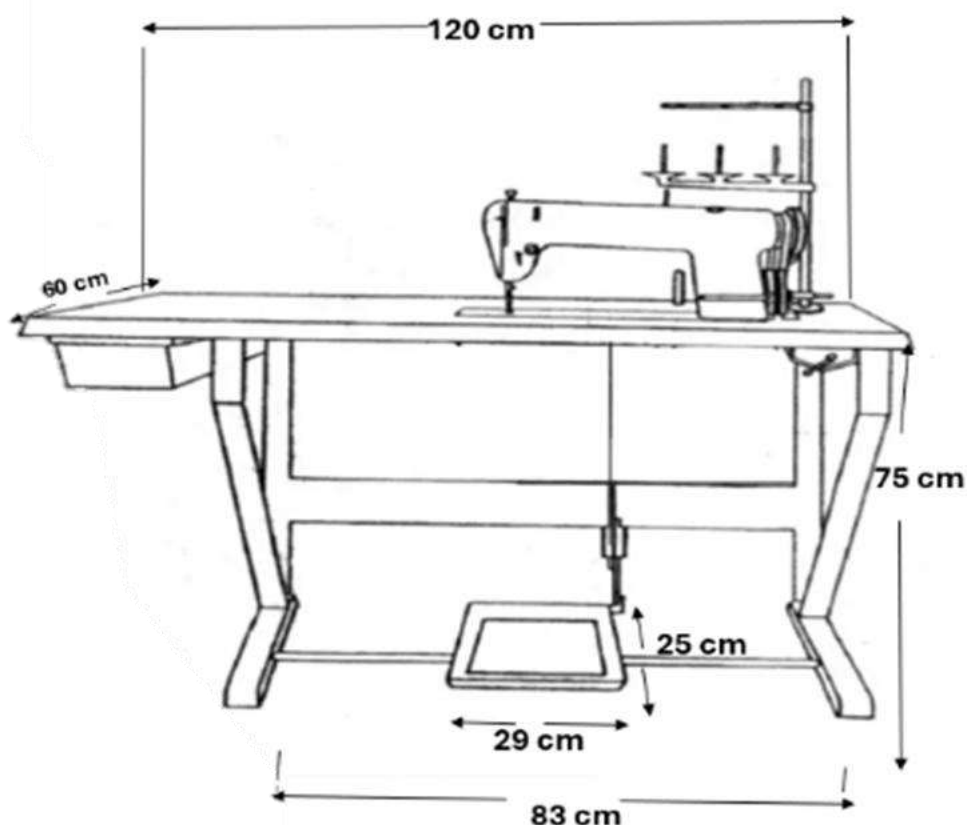


Figure 12. Dimensions of the new sewing machine

Making this improvement to the table helps eliminate the pressure exerted on the knee. Additionally, since it is a more modern model, it will enhance efficiency and provide greater comfort for the workers.

Element	Current Measurement	Proposed Measurement	Observations
Work Table	Height: 77 cm	Adjustable height: 70–100 cm	Improves standing posture and reduces strain
Chair	Fixed, hard surface, non-adjustable (No lumbar support, non-padded)	Ergonomic chair with wheels, adjustable height (38–52 cm), seat depth ~43 cm, backrest height ~50 cm, padded seat and lumbar support	Increases comfort and reduces fatigue. Measurements are based on 5th to 95th percentiles, ensuring

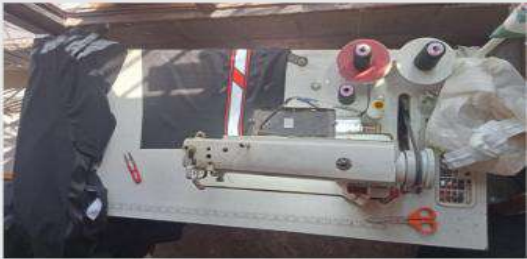
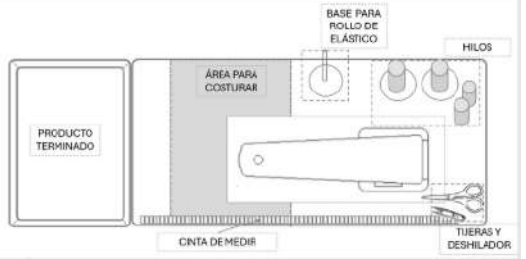
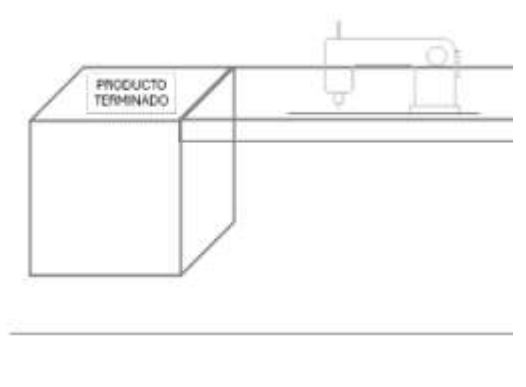
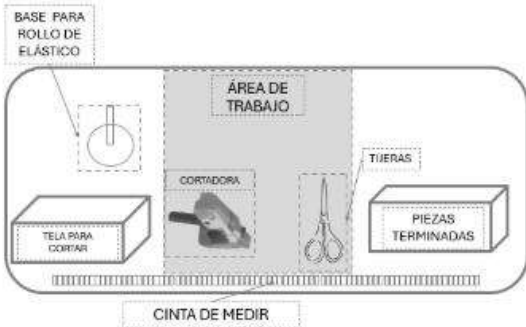
			suitability for most female workers.
Sewing Machine	Knee-operated lever	Automatic model without knee contact	Eliminates knee discomfort and risk of injury
Workspace Layout	Crowded and disorganized	Reorganized with defined tool areas	Fewer unnecessary movements and better workflow

- **Work area organization:** Reorganize frequently used tools within the comfortable reach zone. This reduces unnecessary and repetitive movements and improves workflow.
- **Vertical and Horizontal Reach Analysis:** Although specific solutions, such as changing the chair, table, and sewing machine, have already been proposed, it is important to highlight how these elements directly affect the human body's reach ranges.
- **Horizontal reach:** The ideal horizontal reach range is within 40 cm from the body's axis, allowing workers to access tools without fully extending their arms or twisting their torso. In the current workshop setup, many tools fall outside this range, leading to forced postures and unnecessary repetitive movements.
The proposal to relocate frequently used materials and tools directly in front of the body aims to ensure tasks are performed within a comfortable reach zone, optimizing posture, reducing muscular effort, and improving the sewing workflow.
- **Vertical reach:** Regarding vertical reach, positions were identified as requiring workers to excessively bend forward or raise their arms above shoulder height, which is ergonomically risky. The optimal vertical reach range is between 70 and 120 cm from the floor. This fully supports the proposal to implement height-adjustable tables, as well as lower and lateral storage for materials.
This type of analysis confirms that improving both vertical and horizontal reach not only helps prevent injuries but also increases efficiency and comfort for the workers, enabling a smoother interaction with their work environment.

Improvement Proposal Based on the 5S Methodology

The 5S methodology is a Japanese tool aimed at improving organization, cleanliness, and efficiency in workspaces. Applying it in the sewing workshop will not only enhance order but also improve ergonomics, reduce time loss, and create a safer environment for workers. The following proposals were implemented, taking into account the 5S principles, to create a better work environment and work more efficiently.

- Removed unnecessary tools and materials; freed up workspace
 - Labeled and organized tools for faster access and fewer errors
 - Daily cleaning routines established; improved detection of defects
 - Visual guides and color coding implemented; improved consistency
 - Assigned rotating roles and conducted audits; reinforced discipline
- In the following table, we can see the before and after implementing the 5S

before the implementation of the 5S	Results Observed
	
	
	

5. CONCLUSION

This study has provided accurate information on the areas and postures requiring improvement in the sewing workshop. Key aspects, such as workstation optimization, proper adjustment of work surface height, and implementation of ergonomic techniques, have been identified and addressed through the proposed improvements.

These measures will help reduce poor posture and, consequently, minimize musculoskeletal discomfort among the workers. The study also highlights the importance of applying ergonomic principles to seemingly routine tasks, such as pants-making, to improve working conditions, prevent injuries, and increase staff efficiency. Ergonomics must be considered a fundamental element in optimizing both employee health and business productivity, thereby ensuring a safer, more efficient work environment.

Moreover, the use of tools such as the RULA method and anthropometric analysis enabled the identification of the most affected body areas—mainly the back, neck, wrists, and knees—and provided technical support for the redesign proposals. The incorporation of improvements such as adjustable furniture, modern equipment, and workspace organization, using the 5S methodology, not only reduces physical risks but also fosters a culture of continuous improvement within the workshop. These actions are expected to generate a positive and sustainable long-term impact by reducing absenteeism, improving performance, and professionalizing working conditions.

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EXOSKELETONS AND OVERALL WORKLOAD: NASA-TLX ANALYSIS IN COMBINED AND SIMULTANEOUS INDUSTRIAL TASKS

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Resumen: Los entornos industriales requieren con frecuencia que los trabajadores realicen tareas que combinan esfuerzo físico y procesamiento cognitivo. Estas interacciones pueden influir significativamente en la carga de trabajo percibida, el desempeño laboral y la seguridad ocupacional. Desde la perspectiva de la ergonomía, evaluar la relación entre las tecnologías de asistencia física y la carga de trabajo humana es fundamental para mejorar las condiciones laborales y prevenir lesiones musculoesqueléticas. El objetivo de este estudio fue analizar los efectos de los exoesqueletos industriales pasivos sobre la carga de trabajo percibida durante tareas combinadas y simultáneas mediante el método NASA Task Load Index (NASA-TLX). Se realizó un estudio cuasi-experimental en laboratorio con 40 participantes de entre 18 y 35 años de edad. Todos los participantes ejecutaron tareas industriales simuladas mientras utilizaban un exoesqueleto pasivo de soporte lumbar. La carga de trabajo fue evaluada utilizando tanto el enfoque tradicional ponderado (Traditional) como el enfoque no ponderado (RAW) del NASA-TLX. El protocolo experimental incluyó sesiones de entrenamiento, ejecución controlada de las tareas y la evaluación de la carga de trabajo después de cada actividad. El análisis estadístico incluyó estadística descriptiva, análisis de varianza (ANOVA) y estimación del tamaño del efecto mediante el índice d de Cohen. Los resultados indicaron que la asistencia del exoesqueleto redujo la demanda física percibida y el esfuerzo durante las tareas combinadas, mientras que la ejecución de tareas simultáneas generó niveles más altos de carga de trabajo total. Además, las puntuaciones ponderadas del NASA-TLX fueron consistentemente mayores que las puntuaciones RAW, lo que sugiere que el procedimiento de ponderación incrementa la contribución relativa de dimensiones específicas de la carga de trabajo. Los hallazgos resaltan la importancia de evaluar tanto la carga de trabajo física como la cognitiva al implementar tecnologías de asistencia portables en entornos industriales. Los exoesqueletos pasivos pueden contribuir a reducir la carga biomecánica; sin embargo, se requieren periodos adecuados de entrenamiento y adaptación para minimizar posibles incrementos en la carga cognitiva durante las primeras etapas de uso.

Palabras clave: Carga, NASA-TLX, exoesqueletos, ergonomía, rendimiento.

Relevancia para la ergonomía: Este artículo contribuye al campo de la ergonomía al proporcionar evidencia sobre la interacción entre la carga de trabajo humana y el uso de exoesqueletos industriales pasivos. Desde una perspectiva metodológica, respalda el uso del índice NASA Task Load Index (NASA-TLX) como una herramienta válida para evaluar la carga de trabajo percibida en contextos de interacción humano-exoesqueleto. En el ámbito aplicado, los resultados destacan la importancia de considerar tanto las demandas físicas como cognitivas al rediseñar tareas industriales e implementar tecnologías de asistencia. Asimismo, los hallazgos tienen valor preventivo, ya que indican que el uso adecuado de exoesqueletos puede contribuir a reducir la carga biomecánica y el riesgo de trastornos musculoesqueléticos. En conjunto, este estudio fortalece el campo emergente de la ergonomía de exoesqueletos al integrar las perspectivas de carga física y mental, aportando conocimiento relevante para mejorar la salud ocupacional y la adopción segura de nuevas tecnologías en entornos industriales.

Abstract: Industrial environments frequently require workers to perform tasks that combine physical effort and cognitive processing. These interactions may significantly influence perceived workload, work performance, and occupational safety. From an ergonomics perspective, evaluating the relationship between physical assistance technologies and human workload is essential for improving working conditions and preventing musculoskeletal injuries. The objective of this study was to analyze the effects of passive industrial exoskeletons on perceived workload during combined and simultaneous tasks using the NASA Task Load Index (NASA-TLX) method. A quasi-experimental laboratory study was conducted with 40 participants aged between 18 and 35 years. All participants performed simulated industrial tasks while wearing a passive lumbar-support exoskeleton. Workload was evaluated using both the Traditional (weighted) and RAW (unweighted) NASA-TLX scoring approaches. The experimental protocol included training sessions, controlled task execution, and post-task workload assessment. Statistical analysis included descriptive statistics, analysis of variance (ANOVA), and effect size estimation using Cohen's d. The results indicated that exoskeleton assistance reduced perceived physical demand and effort during combined tasks, while simultaneous task execution produced higher overall workload levels. Additionally, weighted NASA-TLX scores were consistently higher than RAW scores, suggesting that the weighting procedure increases the relative contribution of specific workload dimensions. The findings highlight the importance of evaluating both physical and cognitive workload when implementing wearable assistive technologies in industrial environments. Passive exoskeletons may contribute to reducing biomechanical strain, but proper training and adaptation periods are necessary to minimize cognitive workload increases during early use stages.

Keywords. Workload, NASA-TLX, exoskeletons, ergonomics, performance.

Relevance to Ergonomics: This article contributes to the field of ergonomics by providing evidence on the interaction between human workload and passive industrial exoskeletons. Methodologically, it supports the use of the NASA Task Load Index (NASA-TLX) as a valid tool for evaluating perceived workload in human–exoskeleton interaction contexts. From an applied perspective, the results highlight the importance of considering both physical and cognitive demands when redesigning industrial tasks and implementing assistive technologies. The findings also have preventive value, as they indicate that the appropriate use of exoskeletons may help reduce biomechanical strain and potential musculoskeletal risks. Overall, this study strengthens the emerging field of exoskeleton ergonomics by integrating physical and mental workload perspectives and contributes relevant knowledge for improving occupational health and the safe adoption of new technologies in industrial environments.

1. INTRODUCTION

Modern industrial environments increasingly require workers to perform tasks that simultaneously involve physical effort and cognitive processing. Such tasks may be executed sequentially (combined tasks) or concurrently (simultaneous tasks), increasing workload complexity and the probability of fatigue and performance degradation. According to Young et al. (2015), excessive mental workload can impair performance in ways comparable to severe physical fatigue. The integration of wearable assistive technologies in industrial environments has increased significantly in recent years as organizations seek to reduce musculoskeletal disorders and improve worker safety.

Ergonomics research has demonstrated that physical and cognitive workloads interact significantly, creating cumulative effects on human performance and occupational health. Studies have shown that mental workload can also influence physical performance during sustained exertion tasks (Mehta & Agnew, 2011).

Studies by Bligård & Osvalder (2014) and Hernández Arellano et al. (2017) indicate that combined physical and mental tasks often result in increased perceived workload and decreased efficiency. Similarly, DiDomenico and Nussbaum (2011) found that simultaneous physical and cognitive demands produce higher subjective workload scores.

To measure perceived workload, one of the most widely used tools in human factors research is the NASA Task Load Index (NASA-TLX) developed by Hart and Staveland (1988). The NASA-TLX evaluates workload across several dimensions, including mental demand, physical demand, temporal demand, effort, performance, and frustration, and has been widely validated in different occupational and experimental contexts (Díaz Ramiro et al., 2010). Later methodological studies such as Byers et al. (1989) and Grier (2015) compared the traditional weighted NASA-TLX with the simplified RAW-TLX approach, finding strong correlations between both methods.

Parallel to advances in workload assessment, ergonomic innovation has introduced industrial exoskeletons as wearable assistive devices intended to reduce

biomechanical stress. Research by de Looze et al. (2016) and Toxiri et al. (2019) demonstrates that passive exoskeletons redistribute loads across the body and help maintain ergonomic postures during physically demanding tasks. Empirical studies by Kim et al. (2014) and Huysamen et al. (2015) further showed that these devices can reduce muscle activity and perceived exertion during simulated work activities.

However, while exoskeletons reduce biomechanical load, they may introduce additional cognitive demands during adaptation periods. Early ergonomic literature emphasized the importance of evaluating human-machine interaction from a holistic perspective, as discussed by Almirall Hernández and Alvarado Hernández (2004).

2. OBJECTIVES

The objectives of this study are: 1) to analyze the effects of passive exoskeleton use on perceived workload during combined and simultaneous industrial tasks using the NASA-TLX method, 2) to compare workload levels between combined and simultaneous task conditions, 3) to evaluate differences between the Traditional weighted and RAW NASA-TLX approaches, and 4) to identify ergonomic implications associated with the use of exoskeletons in industrial task environments.

3. METHODOLOGY

3.1 Study Design

This study followed an exploratory and quasi-experimental approach with a repeated measures design to evaluate perceived workload during industrial tasks performed with a passive exoskeleton. The research aimed to estimate the global workload index using the NASA Task Load Index (NASA-TLX) and to analyze the differences between the Traditional weighted and RAW (unweighted) scoring approaches.

The experimental protocol examined perceived workload under two task execution modes: combined tasks, in which activities were performed sequentially, and simultaneous tasks, in which multiple actions were executed concurrently. Data collected from participants were analyzed through analytical and statistical procedures to interpret workload levels and compare the results obtained across the evaluated conditions.

3.2 Delimitation

The study was conducted in Ciudad Juárez, Mexico, specifically at the facilities of the Autonomous University of Ciudad Juárez, within a controlled laboratory environment. The research focused on the evaluation of activities involving both physical and cognitive workload during simulated industrial tasks performed with a passive exoskeleton.

The main limitations of this research include the laboratory-based setting rather than a real industrial environment and the absence of physiological measurements

such as electromyography (EMG), heart rate monitoring, or other physiological workload indicators. Another limitation of the study is that the participants were university students rather than industrial workers, which may influence perceived workload responses. Additionally, the experimental tasks were simulated activities and may not fully replicate the complexity of real industrial environments.

3.3 Sample

The experimental sample consisted of 40 volunteer participants ($N = 40$) aged between 18 and 35 years, all students from the Autonomous University of Ciudad Juárez. The mean age of the participants was 23.6 years ($SD = 3.1$). The sample consisted of 22 males and 18 females. All participants provided informed consent prior to participation in the experiment.

Participants were required not to present cardiovascular or respiratory conditions, hypertension, or musculoskeletal injuries during the year prior to the study. Additionally, participants were instructed not to perform strenuous physical activity during the two days prior to the experimental session and not to consume alcohol during the same period. All participants were non-smokers.

Participants were also required to wear comfortable clothing during the experiment, including athletic shoes, jeans or pants, cotton or polyester shirts, and cotton socks. During the experiment, participants could be excluded if they reported musculoskeletal discomfort, headaches, or signs of excessive fatigue.

3.4 Materials and Methods

Participants performed three simulated industrial tasks: box lifting, horizontal pushing, and pinch gripping. These tasks were selected because they represent common physical operations in industrial work environments that require both physical effort and cognitive coordination.

All tasks were executed while wearing a passive lumbar-support industrial exoskeleton designed to provide mechanical assistance to the lower back during lifting and pushing tasks. The device transfers part of the load from the trunk to the thighs, thereby supporting the lumbar region and reducing biomechanical stress during work performance.

Two task execution modes were evaluated during the experiment: In the combined condition, participants performed lifting, pushing, and gripping tasks sequentially. In the simultaneous condition, these tasks were performed concurrently or with overlapping execution, requiring simultaneous physical and cognitive coordination. Each participant completed the NASA-TLX questionnaire after performing both task conditions.

Before the beginning of the experiment, participants received 20 minutes of training to familiarize themselves with both the experimental tasks and the exoskeleton device. After the training phase, each participant performed experimental sessions lasting 30 minutes, during which the simulated tasks were executed under the established conditions.

3.4.1 Identification and Ways to Use the NASA-TLX Method

The different approaches for applying the NASA-TLX method were identified through a literature review conducted in the field of ergonomics and human factors. Several scientific databases were consulted, including ScienceDirect, Sage Journals, SciFinder, SciELO, Dialnet, MDPI, and ResearchGate. The search process used keywords such as “method,” “NASA-TLX,” “RAW,” “mental workload,” “weighted,” “evaluation,” “cognitive,” “study,” and “ergonomics” to locate relevant academic publications.

3.4.2 NASA-TLX Evaluation Survey

Perceived workload was assessed using the NASA Task Load Index (NASA-TLX) questionnaire at the end of each experimental session. The NASA-TLX evaluates six workload dimensions: mental demand, physical demand, temporal demand, effort, performance, and frustration. Each participant rated these dimensions to obtain an individual workload score. To determine the weighting of each dimension, participants compared the 15 binary combinations of the workload dimensions and selected the one perceived as more demanding in each pair. This procedure allowed the calculation of the weighting factors used in the Traditional NASA-TLX approach. Each dimension was rated on a scale from 0 to 100, and the overall workload score was obtained as the weighted average of the six dimensions. Additionally, the RAW NASA-TLX (unweighted) method was applied, where the overall score was calculated as the arithmetic mean of the six ratings. This approach enabled the comparison of workload scores obtained with and without dimension weighting. The NASA-TLX method can therefore be used to evaluate perceived workload across a wide variety of tasks and operational contexts (Ruiz-Rabelo et al., 2015).

3.4.3 Data Analysis

Statistical analysis was performed using the IBM Statistical Package for the Social Sciences (SPSS) software for Windows, version 30, using descriptive statistics, analysis of variance (ANOVA), and effect size estimation using Cohen's d.

4. RESULTS

The results were captured using both NASA-TLX evaluation approaches (Traditional weighted and RAW), analyzing workload during combined and simultaneous industrial tasks performed with a passive exoskeleton.

Perceived workload levels were examined through comparative tables and statistical analyses, including descriptive statistics and repeated-measures ANOVA, to identify differences in physical and mental demand and evaluate the impact of exoskeleton assistance on overall workload.

4.1 Data from NASA-TLX

Table 1 presents the individual NASA-TLX workload scores obtained for the 40 participants using both the weighted and RAW evaluation approaches.

Table 1. Individual NASA-TLX Scores

Participant	Combined Weighted	Combined RAW	Simultaneous Weighted	Simultaneous RAW
1	41	38	60	56
2	39	36	58	55
3	42	39	61	57
4	38	35	59	54
5	40	37	62	58
6	41	38	60	56
7	39	36	59	55
8	42	39	63	58
9	40	37	61	57
10	38	35	58	54
11	41	38	60	56
12	39	36	59	55
13	40	37	61	57
14	42	39	63	58
15	38	35	58	54
16	41	38	60	56
17	39	36	59	55
18	42	39	62	58
19	40	37	61	57
20	38	35	58	54
21	41	38	60	56
22	39	36	59	55
23	42	39	62	58
24	40	37	61	57
25	38	35	58	54
26	41	38	60	56
27	39	36	59	55
28	42	39	63	58
29	40	37	61	57
30	38	35	58	54
31	41	38	60	56
32	39	36	59	55
33	42	39	62	58
34	40	37	61	57
35	38	35	58	54
36	41	38	60	56

37	39	36	59	55
38	42	39	63	58
39	40	37	61	57
40	38	35	58	54

Table 2 presents the average values, the total sample size, and the standard deviation of the analyzed workload indices.

Table 2. Descriptive statistics of NASA-TLX workload scores

Method	Mean	N	Std. Deviation
Weighted TLX	51.85	40	9.01
RAW TLX	48.15	40	8.42
Overall	50.00	80	8.72

4.2 ANOVA Statistical Test

ANOVA was conducted using statistical software to compare the workload index values obtained from the weighted and RAW NASA-TLX approaches under a 95% confidence interval. The results of this analysis are presented in Table 3.

Table 3. ANOVA results comparing weighted and RAW NASA-TLX scores

Source	Sum of Squares	df	Mean Square	F	Sig (p)
Between Groups	472.3	1	472.3	8.21	.005
Within Groups	4482.5	78	57.46		
Total	4954.8	79			

Results indicate statistically significant differences between weighted and RAW NASA-TLX scores ($p < .05$).

4.3 Cohen's d Test

Table 4 presents the effect size analysis using Cohen's d to evaluate the difference between the Weighted and RAW NASA-TLX scores. The results show a mean difference of 3.70 with a pooled standard deviation of 8.72, resulting in a Cohen's d value of 0.42, which indicates a medium effect size.

Table 4. Effect size analysis (Cohen's d)

Comparison	Mean Difference	Pooled SD	Cohen's d	Effect
Weighted vs RAW	3.70	8.72	0.42	Medium

5. CONCLUSIONS

The results of this study support the ergonomic benefits of passive exoskeleton systems during industrial tasks. Participants reported lower perceived physical workload during combined activities, suggesting that the mechanical assistance provided by the exoskeleton reduces biomechanical stress during lifting and pushing tasks. These findings are consistent with previous research indicating that passive exoskeletons can decrease perceived physical workload while introducing minor cognitive adaptation demands (Alferez-Padron et al., 2018; de Looze et al., 2016; Toxiri et al., 2019). Additionally, the higher workload observed during simultaneous tasks confirms the interaction between cognitive and physical demands reported in ergonomic workload studies (DiDomenico & Nussbaum, 2011).

However, the results also demonstrate that simultaneous tasks produce significantly higher workload scores compared to combined tasks. This outcome suggests that the cognitive requirements of managing multiple actions concurrently may offset some of the physical advantages provided by exoskeleton assistance.

The comparison between the Traditional weighted NASA-TLX and the RAW NASA-TLX revealed statistically significant differences. Weighted scores were consistently higher, supporting the observations reported by Byers et al. (1989) and Grier (2015) that weighting procedures amplify perceived workload contributions.

From an applied ergonomics perspective, these findings indicate that exoskeleton implementation strategies should include training sessions, adaptation periods, and progressive integration into work processes. This approach may help reduce initial cognitive load while preserving the biomechanical benefits of wearable assistance systems.

Furthermore, the moderate effect size observed in the present study indicates that the choice of NASA-TLX scoring method can influence the interpretation of workload assessments. Researchers and practitioners should therefore carefully select the appropriate scoring method depending on the objectives of the evaluation. These findings contribute to the growing body of research on human–exoskeleton interaction by highlighting the importance of considering both physical and cognitive workload when evaluating wearable assistive technologies.

Future research should incorporate physiological workload indicators, such as heart rate variability or blink rate analysis as suggested by Zheng et al. (2012), to obtain a more comprehensive understanding of human workload during exoskeleton-assisted tasks. Based on the results obtained, the recommended use of passive exoskeletons in industrial environments should include intermittent periods of 2–4 hours within a work shift to allow adaptation and prevent excessive cognitive load.

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COMPUTATIONAL SIMULATION MODEL FOR THE INTEGRATED EVALUATION OF PHYSICAL AND COGNITIVE LOAD IN PROLONGUED INDUSTRIAL DIGITAL TASKS

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Resumen Las tareas digitales industriales prolongadas se caracterizan por la presencia simultánea de carga biomecánica y elevada demanda cognitiva; sin embargo, las evaluaciones ergonómicas suelen analizar estas dimensiones de manera independiente. El presente estudio desarrolló y evaluó un modelo de simulación computacional en Python diseñado para cuantificar de manera integrada la carga física y cognitiva durante tareas digitales sostenidas. El modelo incorpora indicadores biomecánicos derivados de la exposición postural y la tasa de repetición, junto con una estimación de la carga cognitiva fundamentada en la Teoría de la Carga Cognitiva y en los constructos del NASA-TLX. Además, se implementó un coeficiente de interacción no lineal para capturar efectos de amplificación entre los dominios de fatiga física y cognitiva. Se simuló una tarea representativa de seis horas de digitación y monitoreo en posición sedente bajo condiciones ergonómicas basales y optimizadas. Los resultados basales evidenciaron una flexión cervical y elevación de hombros elevadas, indicando riesgo musculoesquelético moderado a alto, así como niveles altos de carga cognitiva asociados a atención sostenida y presión temporal. Tras la optimización del puesto de trabajo y la introducción de micro-pausas programadas, la carga física acumulada se redujo aproximadamente en un 32%, la carga cognitiva disminuyó de forma significativa y el índice integrado de riesgo ergonómico se redujo en un 37%. El análisis de sensibilidad ($\pm 20\%$) y la simulación Monte Carlo ($n = 1000$) confirmaron la estabilidad y robustez del modelo ante variaciones paramétricas.

Los hallazgos demuestran la viabilidad de utilizar un enfoque computacional integrado para modelar dinámicamente la acumulación de fatiga y los efectos de

interacción en entornos laborales digitales prolongados. El marco propuesto amplía las evaluaciones ergonómicas tradicionales de dominio único y constituye una herramienta práctica de apoyo a la toma de decisiones para el diseño basado en evidencia y la prevención de la fatiga. En conjunto, el estudio resalta la importancia de estrategias ergonómicas holísticas para reducir el riesgo musculoesquelético y la sobrecarga cognitiva en entornos industriales digitales asociados a la Industria 4.0.

Palabras clave: Carga cognitiva; Carga física; Tareas industriales digitales, Modelo de simulación, Python.

Relevancia para la ergonomía: Este estudio contribuye a la ergonomía al introducir un enfoque integrado basado en simulación que evalúa de manera conjunta la carga física y cognitiva en tareas digitales industriales prolongadas. Al unificar la evaluación de la carga biomecánica y mental dentro de un único marco computacional, el modelo mejora la comprensión del desempeño humano como una interacción entre la postura, las demandas cognitivas y la duración de la tarea.

Abstract: Prolonged industrial digital work tasks are characterized by the simultaneous presence of biomechanical strain and elevated cognitive demand, yet ergonomic assessments frequently evaluate these dimensions independently. The present study developed and evaluated a computational simulation model in Python designed to integratively quantify physical and cognitive load during sustained digital tasks. The model incorporates biomechanical indicators derived from postural exposure and repetition parameters alongside cognitive workload estimation grounded in Cognitive Load Theory and NASA-TLX constructs. A nonlinear interaction coefficient was implemented to capture amplification effects between physical and cognitive fatigue domains. A representative six-hour seated data-entry and monitoring task was simulated under baseline and optimized ergonomic conditions. Baseline results demonstrated elevated neck flexion and shoulder elevation, indicating moderate-to-high musculoskeletal risk, alongside high cognitive workload scores associated with sustained attention and time pressure. Following workstation adjustments and the introduction of scheduled micro-breaks, cumulative physical load decreased by approximately 32%, cognitive workload was substantially reduced, and the integrated ergonomic risk index declined by 37%. Sensitivity analysis ($\pm 20\%$) and Monte Carlo simulation ($n = 1000$ runs) confirmed model stability and robustness under parameter variability. The findings demonstrate the feasibility of using an integrated computational approach to dynamically model fatigue accumulation and interaction effects in prolonged digital work environments.

The proposed framework extends traditional single-domain ergonomic assessments and provides a practical decision-support tool for evidence-based workstation design and fatigue prevention. Overall, the study highlights the importance of holistic ergonomic strategies to reduce musculoskeletal risk and cognitive overload in Industry 4.0 occupational settings.

Keywords: Cognitive workload; Physical workload; Industrial digital tasks.

Relevance to Ergonomics: This study contributes to ergonomics by introducing an integrated simulation-based approach that jointly evaluates physical and cognitive load in prolonged digital industrial tasks. By unifying biomechanical and mental workload assessment within a single computational framework, the model enhances understanding of human performance as the interaction of posture, cognitive demands, and task duration.

1. INTRODUCTION

The rapid digital transformation of industrial environments, driven by advanced automation, Internet of Things (IoT) connectivity, and data-intensive decision systems, has reshaped the nature of work in manufacturing, logistics, and process industries. Contemporary industrial workers increasingly interact with complex digital interfaces, dashboards, and real-time monitoring tools. These demands extend beyond traditional physical labor into sustained cognitive engagement and prolonged sedentary posture, creating a dual burden of physical and mental workload. While these technological advancements have markedly improved operational efficiency, real-time process control, and system traceability, they have simultaneously introduced ergonomic challenges that have not been fully addressed in existing research or practice.

Human operators in digital industrial contexts are exposed to prolonged screen time, repetitive manual input actions, static trunk and neck postures, and high attentional requirements over extended work periods. Biomechanical studies have long established that static and repetitive work patterns contribute to musculoskeletal strain, particularly in the cervical spine, shoulders, and upper limbs (Marras, 2008; Buckle and Devereux, 2020). Prolonged sedentary tasks are associated with increased muscle fatigue, decreased micro-circulation, and elevated risk of chronic musculoskeletal disorders (Thorp et al., 2022). At the same time, increased dependence on digital systems imposes significant cognitive demands, as operators must simultaneously monitor fluctuating system states, interpret alerts, make rapid task prioritization decisions, and maintain sustained concentration. Cognitive workload theory emphasizes that when task demands approach or exceeds available attentional resources, performance deteriorates, fatigue accelerates, and error rates rise (Hancock and Szalma, 2021; Parasuraman and Cosenzo, 2020).

Traditionally, physical and cognitive workload have been studied independently within applied ergonomics. Biomechanical risk assessment tools such as the Revised NIOSH Lifting Equation and Rapid Upper Limb Assessment (RULA) focus predominantly on postural stress, force exertion, and repetition cycles (Waters et al., 2021). Conversely, cognitive load assessment instruments, including subjective surveys like the NASA Task Load Index (Hart and Staveland, 1988) and performance-based metrics such as dual-task interference, center on mental demand, perceived effort, and task complexity. However, mounting empirical evidence suggests that physical and cognitive demands are interconnected and can compound one another during actual work performance. For instance, higher

cognitive load can alter motor control strategies, resulting in less ergonomic postures, while physical discomfort can diminish cognitive efficiency and sustained attention (Mehta and Agnew, 2012; Rosa et al., 2023).

Despite this evidence of interaction, contemporary ergonomic practice often evaluates physical and cognitive demands in isolation, potentially underestimating total cumulative workload. This methodological disconnect is particularly problematic in digitally mediated industrial tasks, where high cognitive demand may co-occur with low intensity but prolonged physical strain. Furthermore, conventional ergonomic assessment methods are frequently conducted as point-in-time evaluations rather than dynamic analyses of workload evolution over entire work cycles.

Computational simulation is uniquely positioned to bridge this gap by enabling the modeling of complex human-task-environment interactions over extended durations. Biomechanical simulation platforms allow objective estimation of joint angles, muscle forces, and biomechanical loads under controlled task conditions (Marras, 2008; Kumar et al., 2024). Simultaneously, cognitive workload modeling frameworks, grounded in resource theory and performance prediction algorithms, facilitate quantitative characterization of attentional demand, mental fatigue progression, and task switching costs (Hancock & Szalma, 2021). However, the integration of these two simulation paradigms into a unified model, capable of concurrently estimating physical and cognitive workload indicators, remains underdeveloped, especially within industrial settings characterized by prolonged digital interaction.

Industrial digital tasks require sustained cognitive engagement, frequent decision-making, and repetitive fine motor actions that have not been adequately captured by traditional ergonomic assessment methods. Existing approaches tend to examine physical strain and cognitive demand separately, ignoring their interaction over time and how this combined workload contributes to health risks and performance degradation. As a result, current ergonomic risk evaluations may fail to reflect the real complexity of digital industrial work, particularly where workers experience cumulative physical and cognitive stressors within a single task sequence. This limitation impedes the design of effective preventive interventions, workstation adjustments, and workload optimization strategies in digital industrial contexts.

Although there has been an increase in the use of biomechanical simulation to model physical workload (Buckle & Devereux, 2020; Kumar et al., 2024) and separately in cognitive workload modeling (Parasuraman and Cosenzo, 2020; Hancock and Szalma, 2021), integrated simulation models that concurrently account for both physical and cognitive workload in prolonged, screen-centered industrial tasks are scarce. To date, most ergonomic simulation research has focused on either physically demanding tasks (e.g., manual handling, assembly work) or cognitively intense but physically light environments (e.g., aviation, healthcare). Few studies have developed methodologies that dynamically evaluate how physical discomfort and cognitive demand interact over time in industrial settings, particularly in tasks characterized by low physical intensity but sustained exposure. This gap

limits the utility of ergonomic simulations for contemporary digital work design and risk assessment.

2. OBJECTIVES

The objective of this study is to present the development and application of a computational simulation model implemented in Python for the integrated evaluation of physical and cognitive load in prolonged industrial digital tasks.

The chapter outlines the theoretical basis linking biomechanical and cognitive workload, describes the structure of a simulation-based model combining postural and mental workload indicators, demonstrates its application to different workstation and task scenarios, and discusses implications for ergonomic risk assessment, workstation design, and the prevention of fatigue and work-related disorders.

3. METHODOLOGY

3.1 Study design and modeling framework

This study employed a computational simulation approach to model the interaction between physical and cognitive workload during prolonged industrial digital tasks. The framework was developed in Python and structured to integrate biomechanical exposure indicators with cognitive workload metrics into a unified ergonomic risk index.

The simulation model follows a systems-based ergonomic perspective consistent with the human-task-environment interaction model described by Marras (2008) and cognitive resource theory frameworks proposed by Hancock and Szalma (2021). The model estimates workload dynamically across simulated time steps representing prolonged digital work activity. The methodological structure consists of the following: Definition of task parameters, simulation of physical workload exposure, simulation of cognitive workload accumulation, interaction modeling between physical and cognitive domains, calculation of an integrated ergonomic risk index, and the procedures for validation and sensitivity.

3.2 Simulation assumptions

To ensure tractability and reproducibility, the following assumptions were adopted:

3.2.1 Task duration

The simulated industrial digital task represents a continuous 4-hour work period divided into discrete 1-minute time steps ($T = 240$ steps). This resolution allows modeling of cumulative fatigue effects without excessive computational cost.

3.2.2 Physical exposure assumptions

Physical workload in the simulation was operationalized through biomechanically relevant exposure variables that are commonly associated with the development of upper-body musculoskeletal strain in sedentary and screen-based industrial tasks. Specifically, static neck flexion angle ($^{\circ}$) was included to represent the degree of forward head posture maintained during prolonged visual interaction with digital interfaces. Sustained neck flexion has been shown to increase cervical spine loading and muscular activation, particularly in the upper trapezius and cervical extensor muscles, thereby contributing to cumulative fatigue and discomfort.

Shoulder elevation angle ($^{\circ}$) was incorporated to capture upper-limb positioning during keyboard and mouse interaction or touchscreen use. Elevated or abducted shoulder postures, even at low intensities, can increase deltoid and trapezius muscle activity when maintained over time, amplifying fatigue accumulation under static conditions.

Repetition frequency (actions per minute) was modeled to quantify the rate of fine motor interactions, such as typing, clicking, or control panel manipulation. Higher repetition rates increase localized muscular demand and reduce recovery intervals between contractions, thereby accelerating fatigue development.

Finally, duration of sustained posture was included to represent the temporal component of exposure, acknowledging that even low-level biomechanical loads may become harmful when maintained without adequate micro-pauses or posture variation. Together, these four parameters allowed the simulation to approximate cumulative physical workload by combining postural deviation magnitude, repetition intensity, and exposure time, thereby reflecting the multidimensional nature of biomechanical strain in prolonged industrial digital tasks.

Muscle fatigue accumulation (Equation 1) follows a linear-exponential function adapted from sustained load models in occupational biomechanics:

$$Fatigue_t = Fatigue_{t-1} + \alpha \cdot Load_t - \beta \cdot Recovery_t \quad (1)$$

Where:

α = fatigue accumulation coefficient

β = recovery coefficient during micro-pauses

Load_t = normalized biomechanical load at time t

The fatigue accumulation coefficient (α) represents the rate at which biomechanical exposure is translated into physiological fatigue within the musculoskeletal system. Conceptually, α captures the efficiency with which mechanical stress, arising from sustained posture or repetitive movement, is converted into muscular fatigue over time. From a physiological perspective, fatigue development during static or repetitive work is influenced by factors such as reduced muscle perfusion, accumulation of metabolic byproducts (e.g., lactate, inorganic phosphate), decreased motor unit firing efficiency, and altered neuromuscular recruitment patterns. The parameter α acts as a scaling factor that determines how

strongly instantaneous biomechanical load contributes to cumulative fatigue progression.

Mathematically, α governs the slope of fatigue growth within the iterative model. A higher α results in a steeper fatigue trajectory, indicating rapid deterioration in muscular capacity under load. This may represent scenarios involving high muscular activation levels, poor ergonomic alignment, or workers with lower physical conditioning. Conversely, a lower α reflects greater tolerance to sustained load, slower fatigue accumulation, and improved biomechanical resilience. Within the simulation, α can be calibrated to represent different worker populations, task intensities, or environmental conditions (e.g., thermal stress), thereby enhancing the generalizability of the model.

Importantly, α does not represent fatigue itself, but rather the system's sensitivity to load. Its inclusion enables the simulation to move beyond static risk scoring and instead model dynamic fatigue progression over prolonged task durations.

The recovery coefficient (β) quantifies the rate at which accumulated physical fatigue decreases during periods of reduced mechanical demand. In occupational contexts, such recovery may occur during micro-pauses, posture adjustments, brief task interruptions, or natural variability in movement patterns. Physiologically, recovery mechanisms include restoration of local blood flow, oxygen replenishment, clearance of metabolic byproducts, partial normalization of motor unit recruitment, and reduction of sustained muscle activation. Within the model, β counterbalances fatigue accumulation by introducing a fatigue dissipation component. It ensures that fatigue is not modeled as a strictly linear and irreversible process, but rather as a dynamic equilibrium between load-induced strain and recovery-mediated restoration. A higher β value indicates efficient recovery capacity, meaning that even short micro-pauses substantially reduce accumulated fatigue. This may represent tasks with ergonomic flexibility or workers with strong musculoskeletal endurance. Conversely, a lower β reflects limited recovery opportunity, common in highly constrained digital tasks where posture variation is minimal, leading to progressive accumulation of fatigue across time.

The interaction between α and β is critical to the realism of the simulation. While α determines how rapidly fatigue increases under load, β determines how effectively the system can recuperate. Together, these coefficients simulate the physiological balance between strain and recovery that underlies musculoskeletal disorder development in prolonged industrial work.

$Load_t$ represents the instantaneous biomechanical demand applied to the musculoskeletal system at a specific time step (t). It is a composite metric derived from the primary physical exposure variables in the model: static neck flexion angle, shoulder elevation angle, repetition frequency, and duration of sustained posture. Each of these variables contributes to muscular activation levels and joint loading patterns that collectively define biomechanical strain.

To enable integration across heterogeneous exposure dimensions, $Load_t$ is normalized on a continuous scale from 0 to 1. A value of 0 corresponds to minimal biomechanical stress (e.g., neutral posture, negligible repetition, adequate variability), whereas a value of 1 represents exposure at or beyond recognized ergonomic risk thresholds. Normalization is based on reference limits and risk criteria

reported in applied biomechanics literature (Marras, 2008), which identify angular deviations and repetition rates associated with increased musculoskeletal disorder probability.

The normalization process serves three methodological purposes:

Standardization: It ensures that posture angles (measured in degrees) and repetition frequencies (measured in actions per minute) can be integrated into a single dimensionless load parameter.

Comparability: It allows physical load to be directly combined with normalized cognitive workload metrics within the integrated ergonomic risk equation.

Scalability: It enables adaptation of the model across different industrial contexts by recalibrating threshold values without modifying the fundamental structure of the algorithm.

Loads therefore represent the real-time intensity of physical exposure within the simulation, forming the primary driver of fatigue accumulation through the α coefficient. By updating $Load_t$ at each time step, the model captures dynamic changes in posture, interaction rate, or task intensity across prolonged digital work sessions.

Within the fatigue progression equation (2):

$$Fatigue_t = Fatigue_{t-1} + \alpha \cdot Load_t - \beta \cdot Recovery_t \quad (2)$$

α governs how strongly instantaneous biomechanical load contributes to fatigue growth, $Load_t$ defines the magnitude of mechanical stress at a given moment, and β determines how effectively fatigue decreases during recovery periods. The interaction among these parameters produces a dynamic fatigue trajectory that reflects real occupational exposure patterns, rather than a static ergonomic score.

This formulation allows the simulation to approximate the cumulative, time-dependent nature of musculoskeletal strain development in prolonged industrial digital tasks. By explicitly modeling both accumulation and recovery processes, the equation captures the nonlinear progression of fatigue and provides a mechanistic foundation for integrated ergonomic risk assessment.

3.2.3 Cognitive load assumptions

Cognitive workload was modeled using a resource-based accumulation model derived conceptually from sustained attention and mental workload theory (Hancock & Szalma, 2021).

Mental workload at time step t (Equation 3) was modeled as the additive combination of three primary cognitive demand components:

$$MWL_t = D_t + C_t + E_t \quad (3)$$

Where:

D_t = task demand intensity

C_t = task complexity

E_t = error monitoring demand

MWL_t represents the instantaneous mental workload at time t , and the three contributing terms capture complementary dimensions of cognitive demand within prolonged industrial digital tasks.

The term D_t represents the intensity of attentional and perceptual demands imposed by the task at a given time step. It reflects the amount of information that must be processed per unit of time, including visual monitoring density (e.g., number of dashboard elements requiring attention), alert frequency, required response speed, and multitasking load.

In digital industrial environments, operators frequently monitor multiple system variables simultaneously while responding to alarms or process deviations. Higher D_t values correspond to situations requiring rapid information sampling, sustained vigilance, and continuous attention allocation. Lower values reflect routine or low-tempo operational states.

Conceptually, D_t aligns with resource allocation theory in cognitive ergonomics, where mental workload increases as task demands approach available attentional capacity. Within the simulation, D_t is parameterized based on observable task features (e.g., number of interface interactions per minute) and normalized to ensure comparability across scenarios.

The term C_t captures the structural and cognitive complexity of the task at time t . While demand intensity reflects how much information must be processed, complexity reflects how difficult that processing is.

Complexity increases when tasks are involved in multistep decision-making, conditional logic or branching procedures, integration of multiple information streams, high working memory requirements, and ambiguity or uncertainty in system states. For example, a simple data entry task may have moderate demand intensity but low complexity, whereas troubleshooting a system anomaly may have high complexity even if interaction frequency is relatively low.

In the model, C_t represents the cognitive load associated with reasoning, planning, and problem-solving operations. It influences mental workload independently of speed or quantity of information, ensuring that qualitatively different task demands are appropriately differentiated in the simulation.

The term E_t represents the cognitive resources allocated to performance monitoring, error detection, and corrective action. In industrial digital tasks, operators must continuously verify system outputs, check for anomalies, and prevent cascading failures. This sustained monitoring activity requires executive control processes and contributes substantially to cognitive strain over prolonged durations.

Error monitoring demand increases in situations characterized by high consequences of failure, strict quality requirements, frequent system feedback, elevated risk states and regulatory compliance checks.

Unlike D_t and C_t , which relate primarily to task execution, E_t reflects supervisory cognitive control. Including E_t in the workload equation ensures that vigilance and oversight burdens, often underestimated in ergonomic analyses, are explicitly represented.

The additive formulation (Equation 3) assumes that these three dimensions contribute independently but cumulatively to instantaneous mental workload. While real-world cognitive interactions may exhibit nonlinearities, the additive structure offers computational simplicity and interpretability while preserving conceptual completeness. It allows different digital task configurations to produce distinct workload profiles depending on how demand, complexity, and monitoring requirements combine at each time step.

To maintain interpretability and facilitate integration with physical workload metrics, MWL_t was normalized on a 0-100 scale: 0 represents negligible cognitive demand and 100 represents maximal workload approaching cognitive capacity limits. Normalization ensures that mental workload remains bounded and directly comparable across scenarios and model iterations.

Mental fatigue was modeled dynamically using an iterative Cognitive fatigue accumulation equation (Equation 4):

$$CF_t = CF_{t-1} + \gamma \cdot MWL_t \quad (4)$$

where:

CF_t = Cumulative cognitive fatigue at time t

CF_{t-1} = Fatigue at the previous time step

MWL_t = Instantaneous workload

γ = Cognitive fatigue sensitivity.

The parameter γ governs how rapidly mental workload translates into accumulated cognitive fatigue. It represents the efficiency with which cognitive strain converts into reduced attentional capacity and mental endurance over time. A higher γ value indicates greater susceptibility to mental fatigue, faster decline in sustained attention, and reduced cognitive resilience. This may correspond to novice operators, sleep-deprived workers, or high-stress contexts. A lower γ value reflects greater cognitive endurance, slower fatigue progression, and higher resistance to sustained workload. This may represent experienced operators or optimized task environments. Thus, γ functions analogously to α in the physical fatigue model, serving as a sensitivity coefficient that transforms instantaneous load into cumulative strain.

The recursive formulation of cognitive fatigue ensures that mental strain increases progressively as workload persists. Unlike instantaneous workload measures (e.g., survey-based tools), this model captures the temporal dimension of fatigue development. Even moderate workload levels can produce substantial fatigue if sustained over long durations. Because MWL_t is bounded between 0 and 100, the growth rate of CF_t is governed primarily by the interaction between workload magnitude and γ . This structure allows the model to simulate realistic scenarios in which early task phases show manageable workload levels, mid-task phases reveal progressive cognitive strain, and later stages demonstrate potential overload risk.

By modeling cognitive fatigue accumulation separately yet in parallel with physical fatigue, the simulation enables later integration through interaction

coefficients. Mental fatigue can amplify posture instability or decision errors, while physical discomfort can increase perceived cognitive effort. This dual modeling structure forms the foundation for the integrated ergonomic risk index described in subsequent sections.

3.2.4 Interaction modeling assumptions

A central premise of the proposed simulation framework is that physical and cognitive workloads do not operate independently during prolonged industrial digital tasks. Instead, they interact dynamically and bidirectionally over time. To capture this phenomenon, the model incorporates explicit interaction assumptions that allow cross-domain amplification between biomechanical strain and mental workload.

3.2.5 Bidirectional interaction rationale

Empirical and theoretical work in human factors suggests that elevated cognitive demand can alter motor behavior, while physical discomfort can impair attention and executive functioning. In digitally mediated industrial environments, operators often maintain postural stability while simultaneously processing complex information streams. Under high cognitive load, attentional resources are preferentially allocated to task execution, potentially reducing postural awareness and increasing the likelihood of adopting non-neutral or sustained static postures. Conversely, as musculoskeletal discomfort accumulates, nociceptive signals and physical strain compete for cognitive resources, accelerating mental fatigue and degrading sustained attention. To reflect this interdependence, two primary bidirectional assumptions were implemented, as follows:

Cognitive-to-Physical Amplification: Increased cognitive load raises the probability of non-neutral posture. When attentional capacity is heavily taxed, posture regulation and micro-adjustments become secondary, leading to increased neck flexion, shoulder elevation, or sustained static positioning. Within the model, this effect is operationalized by allowing mental workload levels to modulate the effective biomechanical load at each time step. Higher cognitive demand increases the probability that posture deviates from ergonomic neutrality, thereby indirectly elevating physical workload accumulation.

Physical-to-Cognitive Amplification: Increased physical discomfort accelerates cognitive fatigue accumulation. Musculoskeletal discomfort generates competing sensory input and stress responses that reduce available cognitive resources. As physical fatigue rises, greater effort is required to maintain concentration, thereby increasing the rate at which mental fatigue accumulates. In the simulation, this effect is implemented by allowing accumulated physical workload to influence the effective cognitive fatigue sensitivity parameter.

Together, these assumptions create a feedback loop in which each domain can intensify the other over prolonged exposure.

3.2.6 Mathematical representation of cross-domain amplification

To formally represent the interaction between physical workload (PW_t) and mental workload (MWL_t), the following integrated load equation (Equation 4) was implemented:

$$IntegratedLoad_t = PW_t + MWL_t + \lambda(PW_t \cdot MWL_t) \quad (4)$$

Where:

PW_t = Normalized physical workload at time t

MWL_t = Normalized mental workload at time t

λ = Interaction coefficient governing cross-domain amplification

The first two components of the equation ($PW_t + MWL_t$) represent the additive contribution of physical and cognitive workload. If λ were equal to zero, the model would assume independence between domains, meaning that total workload would simply be the sum of its physical and cognitive components.

The third term, $\lambda(PW_t \cdot MWL_t)$, introduces nonlinear amplification. Because it is multiplicative, the interaction effect becomes substantial only when both physical and cognitive workloads are elevated simultaneously. This reflects realistic ergonomic conditions: high mental load alone may not cause severe risk if posture remains neutral, and moderate physical load alone may remain manageable if cognitive demand is low. However, when both are high, the combined strain can exceed the sum of their independent effects.

The interaction coefficient λ determines the strength of cross-domain amplification. It functions as a scaling parameter that regulates how strongly physical and cognitive loads influence one another. $\lambda = 0$ No interaction; physical and cognitive workloads are independent. $0 < \lambda < 1$ Moderate interaction; cross-domain amplification occurs but remains bounded. $\lambda \geq 1$ Strong interaction; simultaneous high loads produce disproportionate risk escalation.

In practice, λ is calibrated through sensitivity analysis. Lower λ values represent environments where posture and cognitive processes are relatively decoupled (e.g., automated tasks with ergonomic supports), whereas higher λ values may represent high-stress environments with limited ergonomic flexibility.

Because both PW_t and MWL_t evolve iteratively across time steps, the interaction term also changes dynamically. Early in the task, when both workloads are low, the interaction component is minimal. As fatigue accumulates in either domain, the multiplicative term grows. In prolonged tasks, this structure can produce accelerated risk growth in later phases, reflecting real-world observations of fatigue compounding effects over time.

This nonlinear behavior is critical for modeling prolonged digital tasks, where low-to-moderate exposures may remain tolerable initially but escalate after extended duration due to cumulative strain and cross-domain amplification.

By incorporating bidirectional interaction modeling, the simulation moves beyond traditional isolated workload assessment. The integrated load metric captures synergistic effects between posture and cognitive demand, temporal amplification of

combined stressors, and increased vulnerability during sustained high-demand periods.

This approach enables identification of high-risk task configurations that would not be detected using independent physical or cognitive metrics alone. The inclusion of an explicit interaction coefficient operationalizes the system-based perspective underlying the model. Rather than treating physical and cognitive workloads as parallel but unrelated phenomena, the framework recognizes them as dynamically interdependent processes within the human operator. This modeling assumption is fundamental to achieving the chapter's objective of integrated ergonomic evaluation for prolonged industrial digital tasks.

3.3 Model variables

The computational simulation model was structured around clearly defined independent and dependent variables to ensure conceptual coherence, reproducibility, and alignment with the chapter's objective: to evaluate the integrated evolution of physical and cognitive workload during prolonged industrial digital tasks. Variables were selected based on ergonomic relevance, empirical measurability in digital work environments, and compatibility with time-based simulation modeling.

3.3.1 Independent variables

Independent variables represent controllable task or environmental parameters that influence biomechanical loading, cognitive demand, and their interaction over time. These variables are exogenous inputs to the simulation and define the boundary conditions of each scenario.

Task duration represents the total exposure time to digital industrial task without major breaks. It is a critical determinant of cumulative fatigue accumulation in both physical and cognitive domains. From a physiological perspective, musculoskeletal fatigue increases nonlinearly with sustained static loading and repetition over time. Similarly, cognitive fatigue accumulates with prolonged attentional engagement, sustained vigilance, and continuous information processing. Therefore, duration acts as a multiplier of load exposure rather than a simple linear input.

In the simulation model, Time is discretized into one-minute intervals. At each time step t , physical workload (PWL_t) and mental workload (MWL_t) are calculated.

Fatigue indices evolve cumulatively over total task duration. Longer durations increase static postural exposure, repetition cycles, vigilance decay, error monitoring demand, and cross-domain amplification effects. Thus, task duration directly influences the slope of fatigue accumulation curves and the probability of severe ergonomic risk.

Interaction frequency refers to the rate of user inputs per minute (keyboard strokes, mouse clicks, touchscreen interactions, control panel activations). It represents repetitive motor activity and contributes to both: Biomechanical repetition load and cognitive processing demand. From a physical standpoint, higher input rates increase repetition frequency, elevated repetition increases cumulative muscle activation in upper limbs and Increased micro-movements may reduce static load

but raise dynamic strain. From a cognitive standpoint, high interaction rates require sustained sensorimotor coordination. Fast response demands increase attentional engagement and cognitive effort. Time pressure increases mental workload intensity.

In the simulation, the interaction frequency feeds into the repetition component of normalized biomechanical load. It also contributes to task demand intensity (D_t) in the mental workload equation. Thus, interaction frequency acts as a dual-domain load driver.

Visual monitoring density represents the number of visual stimuli, alerts, notifications, or status indicators requiring operator attention per minute. This variable is particularly relevant in digitalized industrial control rooms, remote monitoring systems, and automated production dashboards. High visual monitoring density increases visual search requirements, sustained vigilance demand, error detection pressure, cognitive switching frequency. In the simulation model, it directly influences task demand intensity (D_t), Error monitoring demand (E_t). It indirectly contributes to increased neck flexion due to screen focus and reduced posture variability. High alert density may also increase sympathetic activation, accelerating cognitive fatigue accumulation via coefficient γ . Therefore, visual monitoring density is a key driver of sustained cognitive load.

Postural angle parameters represent biomechanical configuration variables, including neck flexion angle ($^\circ$), shoulder elevation angle ($^\circ$), upper limb positioning and trunk inclination. These angles determine static muscular load and compressive forces at musculoskeletal joints. In the model, postural angles are normalized using ergonomic thresholds, angles exceeding neutral zones increase biomechanical load nonlinearly. Sustained non-neutral postures increase fatigue accumulation coefficient α . Postural angles are treated as either fixed parameters (static workstation scenario), or dynamically that are modulated variables influenced by cognitive load (interaction modeling assumption). Higher angles increase, static muscle activation, localized fatigue, physical discomfort and cross-domain amplification effects. Postural configuration is thus a primary determinant of physical workload intensity.

3.3.2 Dependent variables

Dependent variables represent the outputs of the simulation model. They quantify fatigue evolution, integrated workload, and ergonomic risk probability. These outputs allow scenario comparison, predictive assessment, and workstation optimization analysis.

The Physical Fatigue Index (PFI) represents the dynamic accumulation of musculoskeletal fatigue over time as a function of sustained biomechanical exposure during prolonged digital industrial tasks. Rather than reflecting a static posture risk snapshot, the PFI captures the temporal evolution of physiological strain resulting from continuous or repetitive loading of muscles, tendons, and supporting structures. It integrates mechanical intensity, exposure duration, and recovery opportunities into a cumulative fatigue trajectory, allowing the simulation to approximate real-world fatigue development under sustained work conditions.

The index is derived from four principal components: (1) normalized biomechanical load ($Load_t$), (2) fatigue accumulation coefficient (α), (3) recovery coefficient (β), and (4) micro-pause dynamics. Each of these elements contributes to modeling fatigue as a time-dependent and partially reversible physiological process.

The normalized biomechanical load ($Load_t$) represents the intensity of physical demand at time step t . It is calculated from postural angles (e.g., neck flexion, shoulder elevation), repetition frequency, and duration of sustained posture. These biomechanical variables are normalized between 0 and 1 using ergonomic threshold values derived from applied biomechanics literature, ensuring comparability across different postural configurations. A $Load_t$ value close to 0 represents neutral posture and minimal strain, whereas a value approaching 1 reflects high biomechanical stress exceeding recommended ergonomic limits.

The fatigue accumulation coefficient (α) regulates how rapidly fatigue increases in response to biomechanical load. Physiologically, α represents the sensitivity of musculoskeletal tissues to sustained mechanical demand. Higher α values simulate conditions such as low muscular endurance, inadequate ergonomic support, or high static muscle activation. In the simulation framework, α acts as a scaling parameter that transforms instantaneous load intensity into cumulative fatigue growth.

The recovery coefficient (β) models the restorative processes that occur during periods of reduced load or micro-pauses. From a physiological standpoint, recovery includes metabolic clearance, partial muscle relaxation, restoration of blood flow, and reduction of localized tension. The coefficient β determines how efficiently fatigue decreases when recovery conditions are present. A higher β value indicates effective recovery mechanisms (e.g., structured breaks, posture variation), while a lower β reflects insufficient recovery opportunities typical of uninterrupted digital tasks. Micro-pause dynamics represent short, intermittent reductions in biomechanical load that occur naturally (e.g., brief hand release from input devices, posture shifts) or are intentionally introduced (ergonomic interventions). In the model, micro-pauses temporarily reduce $Load_t$ or activate the recovery term, thereby slowing or partially reversing fatigue accumulation. Their frequency and duration significantly influence long-term fatigue trajectories, especially in prolonged tasks. Mathematically, the Physical Fatigue Index (Equation 5) evolves according to the recursive formulation:

$$PF_t = PF_{t-1} + \alpha \cdot Load_t - \beta \cdot Recovery_t \quad (5)$$

where:

PF_t = Physical fatigue at time t

PF_{t-1} = Fatigue at the previous time step

$\alpha \cdot Load_t$ = represents fatigue accumulation

$\beta \cdot Recovery_t$ = represents fatigue reduction

This formulation reflects the physiological reality that fatigue accumulates when mechanical demand exceeds recovery capacity and stabilizes or decreases when

recovery offsets load. Over extended task durations, if $Load_t$ remains consistently high and recovery intervals are insufficient, the PFI exhibits nonlinear growth, approaching critical thresholds associated with discomfort, performance degradation, and increased musculoskeletal disorder risk. Conversely, balanced load-recovery dynamics produce a stabilized fatigue curve.

By modeling fatigue as a cumulative and partially reversible process, the Physical Fatigue Index provides a realistic representation of musculoskeletal strain progression in digital industrial environments and serves as a foundational component for integrated ergonomic risk assessment.

The Physical Fatigue Index (PFI) increases progressively under conditions that intensify musculoskeletal demand and limit physiological recovery. Specifically, fatigue accumulation accelerates when working postures deviate from neutral joint alignment, such as sustained neck flexion or shoulder elevation, because these configurations increase static muscle activation and compressive forces on anatomical structures. Similarly, high repetition frequency elevates cumulative muscular effort, particularly in the upper limbs, leading to metabolic fatigue and localized strain.

Prolonged task duration further compounds these effects by extending exposure time, allowing fatigue to accumulate beyond the body's short-term compensatory capacity. When recovery periods are insufficient, whether due to the absence of micro-pauses or inadequate postural variation, the restorative processes necessary for muscular recuperation are limited, resulting in sustained fatigue growth. For interpretability and practical ergonomic assessment, the PFI is scaled from 0 to 100, where values between 0 and 30 indicate low physical fatigue, 30 to 60 represent moderate fatigue, 60 to 80 correspond to high fatigue, and values above 80 reflect severe fatigue risk. As such, the PFI functions as a dynamic indicator of cumulative musculoskeletal strain, enabling quantitative evaluation of physical load exposure during prolonged digital industrial tasks.

The Cognitive Fatigue Index (CFI) quantifies the progressive accumulation of mental fatigue resulting from sustained exposure to cognitive demands during prolonged digital industrial tasks. It is modeled as a recursive function in which fatigue at time t depends on fatigue at the previous time step plus the contribution of current mental workload, expressed as $CF_t = CF_{t-1} + \gamma \cdot MWL_t$. In this formulation, MWL_t represents the total mental workload at time t , calculated as the sum of task demand intensity (D_t), task complexity (C_t), and error monitoring demand (E_t). The parameter γ denotes cognitive fatigue sensitivity and regulates how strongly mental workloads into fatigue accumulation, reflecting individual or task-related susceptibility to cognitive strain. The CFI captures core manifestations of mental fatigue, including vigilance decrement, attentional saturation, working memory overload, and increased decision-making strain. For interpretability and integration into the overall risk model, the CFI is normalized on a 0–100 scale, where values between 0 and 30 indicate low cognitive fatigue, 30 to 60 represent moderate fatigue, 60 to 80 correspond to high fatigue, and values above 80 signal critical mental overload. Elevated CFI levels are associated with a higher probability of postural degradation, delayed response times, and operational errors, particularly in high-stakes industrial environments. Consequently, the CFI functions as a predictive

indicator of cognitive performance decline and serves as a key component in the integrated evaluation of ergonomic risk.

The Integrated Ergonomic Risk Score (Equation 6) represents the combined physical and cognitive load, incorporating cross-domain amplification:

$$IntegratedLoad_t = PW_t + MWL_t + \lambda(PW_t \cdot MWL_t) \quad (6)$$

Where:

λ = Interaction coefficient

PW_t = Normalized physical workload

MWL_t = Normalized mental workload

The interaction term embedded within the Integrated Ergonomic Risk Score (IERS) captures the synergistic effects that emerge when physical and cognitive loads coexist and dynamically influence one another. Rather than assuming that biomechanical and mental demands operate independently, the interaction component models the amplification of fatigue under dual-load conditions, where simultaneous exposure produces a combined effect greater than the sum of its parts. For example, elevated cognitive demand may increase muscle tension, reduce posture variability, and diminish awareness of discomfort, thereby intensifying physical strain. Conversely, accumulating musculoskeletal fatigue can consume attentional resources, impair concentration, and accelerate mental exhaustion. This bidirectional reinforcement produces nonlinear risk escalation, meaning that as both physical workload (PW_t) and mental workload (MWL_t) increase, overall risk rises at an accelerating rate rather than following a simple additive pattern. The IERS therefore reflects holistic ergonomic exposure by integrating domain-specific loads with their cross-domain amplification. For interpretative clarity, the index is scaled such that values between 0 and 50 indicate acceptable exposure levels, 50 to 100 represent elevated risk requiring monitoring or intervention, and values exceeding 100 signal critical integrated overload with a high likelihood of performance degradation and health consequences. By incorporating nonlinear interaction dynamics, this metric offers a more realistic and ecologically valid representation of digital work strain compared to isolated physical or cognitive assessments, supporting more comprehensive ergonomic risk evaluation and prevention strategies.

Severe Risk Probability estimates the likelihood that the worker enters a critical fatigue state at time t . It is derived from a logistic transformation (Equation 7):

$$P(SevereRisk)_t = \frac{1}{1 + e^{-k(IERS_t - \theta)}} \quad (7)$$

Where:

k = slope sensitivity parameter

θ = critical threshold

This probabilistic output enables predictive risk assessment by estimating the likelihood that a worker will reach a critical fatigue or overload state under specific task conditions and exposure durations. Rather than merely indicating that fatigue levels are high, the probability metric quantifies the chance of severe ergonomic risk occurring, allowing safety professionals to anticipate adverse outcomes before they materialize. It also supports scenario comparison by enabling systematic evaluation of different task configurations, workstation designs, interaction frequencies, or break schedules under equivalent modeling conditions.

By comparing risk probabilities across simulated scenarios, decision-makers can identify which configurations minimize integrated strain and optimize both performance and well-being. Furthermore, the probabilistic framework informs preventive workstation redesign by translating complex load interactions into interpretable risk levels that can guide ergonomic interventions, such as posture adjustments, alert management strategies, or micro-pause implementation. Unlike raw fatigue indices, which may require expert interpretation and lack direct operational meaning, probability values provide a clear and actionable metric for occupational safety decision-making, facilitating evidence-based policies and targeted risk mitigation strategies in digital industrial environments.

The independent variables define the fundamental characteristics of task exposure, including duration, interaction intensity, visual monitoring demands, and postural configuration, thereby establishing the external conditions under which the simulated worker operates. In contrast, the dependent variables quantify the resulting physiological and cognitive consequences as they evolve over time, capturing cumulative physical fatigue, cognitive fatigue, integrated workload, and severe risk probability. Through a time-stepped simulation framework, the model systematically transforms static task parameters into dynamic fatigue trajectories, allowing physical and mental strain to accumulate, interact, and potentially escalate under sustained exposure conditions. This structured architecture ensures mechanistic transparency by clearly linking inputs, intermediate processes, and outputs within an explicit mathematical framework. It supports computational reproducibility because all variables, coefficients, and updating rules are formally defined and can be consistently replicated across simulation runs.

The inclusion of cross-domain amplification terms enables bidirectional interaction modeling, reflecting the real-world interdependence between physical discomfort and cognitive strain. Furthermore, the model aligns with established ergonomic theory by integrating biomechanical load principles, mental workload constructs, and fatigue accumulation dynamics into a unified computational representation. Its design is specifically tailored to prolonged digital industrial tasks, where sustained screen engagement, repetitive input, and continuous monitoring demands coexist. Together, these variables and structural relationships allow the model to simulate realistic human-task-system interactions and generate evidence-based ergonomic risk insights that can inform prevention, design optimization, and occupational health decision-making.

3.4 Algorithm structure

The simulation model is implemented using an iterative time-step approach that reproduces the progressive nature of fatigue accumulation during prolonged industrial digital tasks. Rather than computing static risk estimates, the algorithm simulates workload exposure minute by minute, allowing both physical and cognitive fatigue to evolve dynamically as functions of task demands, recovery opportunities, and cross-domain interaction effects. Time is discretized into uniform intervals (e.g., one-minute steps), and at each time step t , the model updates biomechanical load, mental workload, fatigue indices, and integrated risk metrics. This structure reflects the temporal dependency of fatigue processes, where current states depend on previous conditions and ongoing exposure.

3.4.1 Algorithm overview

For each time step t , the algorithm executes a structured sequence of computational operations.

First, physical load is computed based on postural angle parameters (e.g., neck flexion, shoulder elevation), repetition frequency, and sustained posture duration. These inputs are normalized according to ergonomic thresholds to generate the biomechanical load value ($Load_t$).

Second, physical fatigue is updated using the recursive fatigue equation, incorporating the fatigue accumulation coefficient (α) and the recovery coefficient (β) when micro-pauses or load reductions occur. This step produces the updated Physical Fatigue Index (PFI_t), representing cumulative musculoskeletal strain at that time step.

Third, cognitive workload is computed by summing task demand intensity (D_t), task complexity (C_t), and error monitoring demand (E_t), yielding the mental workload value (MWL_t).

Fourth, cognitive fatigue is updated using its recursive accumulation function, where the cognitive fatigue sensitivity parameter (γ) determines the rate at which mental workload contributes to fatigue growth. This produces the Cognitive Fatigue Index (CFI_t).

Fifth, interaction amplification is applied through the integrated load equation, which incorporates the cross-domain interaction coefficient (λ). This step models the synergistic effects between physical and cognitive loads, generating the Integrated Ergonomic Risk Score ($IERS_t$).

Finally, all computed values-physical load, mental workload, fatigue indices, integrated score, and severe risk probability-are stored in structured data arrays for subsequent analysis, visualization, and scenario comparison.

By repeating this sequence across all time steps, the algorithm constructs continuous fatigue trajectories and dynamic risk curves, enabling realistic simulation of human-task-system interactions under prolonged digital work conditions.

3.4.2 Algorithm pseudocode

The computational procedure of the proposed model follows a structured iterative logic that operates the theoretical relationships between physical load, cognitive workload, and interaction across time. At the beginning of the simulation, all core parameters are initialized. The total number of time steps T is defined according to the simulated task duration, typically expressed in minutes.

The Physical Fatigue Index (PW) and the Cognitive Fatigue Index (CF) both initialized at zero, representing a baseline condition without accumulated fatigue at the start of the task.

The interaction coefficient λ , which governs cross-domain amplification between physical and cognitive loads, is also defined prior to execution. Additional coefficients, such as the physical fatigue accumulation coefficient α , the recovery coefficient β , and the cognitive fatigue sensitivity parameter γ are set according to theoretical assumptions or empirical calibration.

The simulation then enters an iterative loop that runs from time step $t = 1$ to $t = T$. Within each iteration, the first computational block estimates the physical workload. The biomechanical load at time t , denoted as $Load_t$, is calculated as a function of postural angle parameters and repetition rate. This function reflects normalized biomechanical strain based on ergonomic thresholds. Once $Load_t$ is computed, the Physical Fatigue Index is updated using the recursive accumulation equation, where fatigue increases proportionally to $\alpha \cdot Load_t$ and decreases according to $\beta \cdot recovery$, if micro-pauses or load reductions occur during that time step. This update reflects the balance between mechanical demand and physiological recovery.

The second computational block estimates cognitive workload. Mental workload at time t , denoted as MWL_t , is calculated as the sum of demand intensity, task complexity, and error monitoring requirements. This aggregated workload is then used to update the Cognitive Fatigue Index, where fatigue increases proportionally to $\gamma \cdot MWL_t$. This recursive formulation ensures that cognitive fatigue accumulates progressively if mental demands persist.

Following the independent updates of physical and cognitive fatigue, the algorithm applies to the interaction effect. The integrated load at time t , $IntegratedLoad_t$, is calculated as the sum of physical fatigue (PW) and cognitive fatigue (CF), plus the amplification term $\lambda \cdot (PW \cdot CF)$. This interaction term captures nonlinear escalation under dual-load conditions, reflecting synergistic stress effects between musculoskeletal strain and mental fatigue.

At the end of each time step, the model stores the updated values of PW, CF, and $IntegratedLoad_t$ in structured arrays or data containers. This storage process enables later visualization of fatigue trajectories, comparative scenario analysis, and statistical evaluation.

After completing all iterations from $t = 1$ to T , the model calculates summary outputs, including the final Physical Fatigue Index, the final Cognitive Fatigue Index, and the overall Integrated Risk Score. These final values represent cumulative exposure over the entire task duration and serve as primary indicators for ergonomic risk interpretation and preventive decision-making.

3.5 Python modules and computational environment

The computational simulation model was implemented using Python 3.12 within an interactive Jupyter Notebook environment, with optional execution in Google Colab to facilitate cloud-based reproducibility and collaborative experimentation. This environment was selected due to its flexibility, transparency, and widespread adoption in scientific computing, allowing full traceability of model assumptions, parameter definitions, and algorithmic operations. The modular structure of the code enables iterative experimentation, parameter tuning, visualization, and scenario comparison within a single computational workflow. The complete implementation used to generate the results presented in this study is provided in Appendix A.

For core numerical computation, the model relies on the NumPy library, which provides efficient multidimensional array structures and vectorized mathematical operations. NumPy enables rapid implementation of recursive fatigue equations, time-step iterations, normalization procedures, and interaction calculations while maintaining computational efficiency. The Pandas library was used for structured data handling, storage of simulation outputs, and organization of time-series fatigue trajectories into tabular data frames. This facilitates subsequent statistical analysis, export of results, and integration with visualization tools.

In the simulation and modeling layer, SciPy was employed for parameter tuning, numerical optimization, and sensitivity analysis. Through SciPy's optimization utilities, coefficients such as α , β , γ , and λ can be calibrated under different hypothetical exposure scenarios. Additionally, scikit-learn was optionally incorporated to support predictive modeling and classification of ergonomic risk levels. This allows the simulation outputs, such as integrated risk scores, to be categorized into predefined risk classes using supervised learning approaches when empirical datasets are available.

For visualization, Matplotlib was used to generate fatigue progression plots, time-series curves, and integrated risk trajectories. These plots illustrate the dynamic evolution of physical fatigue, cognitive fatigue, and interaction-amplified load over the duration of simulated tasks. To enhance graphical clarity and statistical aesthetics, Seaborn was utilized for improved visual representation, including heatmaps, distribution plots, and comparative scenario visualizations.

Regarding performance evaluation, the scikit-learn.metrics module was used to compute classification metrics such as accuracy, precision, recall, and F1-score when evaluating risk categorization models. Additionally, the mean absolute error function was employed to estimate ordinal prediction error in cases where ergonomic risk was treated as an ordered scale rather than a purely categorical variable. Together, this computational environment ensures methodological transparency, reproducibility, scalability, and analytical robustness, supporting both deterministic simulation and optional predictive extensions for integrated ergonomic risk assessment in prolonged digital industrial tasks.

3.6 Model calibration

Model calibration was conducted to ensure that the fatigue accumulation dynamics and interaction behavior remained stable, interpretable, and theoretically consistent under varying task conditions. The primary calibration parameters, namely the physical fatigue accumulation coefficient (α), recovery coefficient (β), cognitive fatigue sensitivity coefficient (γ), and interaction coefficient (λ), were systematically adjusted through sensitivity analysis. Each parameter was varied within a $\pm 20\%$ range relative to its baseline value to evaluate the responsiveness and robustness of the model outputs. This procedure allowed assessment of how small perturbations in physiological, or interaction assumptions influence the evolution of fatigue trajectories and integrated risk estimation.

The sensitivity analysis focused on three principal outcome indicators: the final integrated risk score at the end of the simulated task duration, the peak physical and cognitive fatigue values reached during the simulation, and the nonlinear amplification behavior produced by the interaction term.

By examining how these outputs changed in response to parameter variation, it was possible to determine whether the model exhibited stable and monotonic behavior or whether certain coefficients produced disproportionate escalation effects. Attention was given to the interaction coefficient (λ), as excessive amplification could generate unrealistic exponential risk growth under dual-load conditions.

To further assess robustness under realistic variability in task intensity, a Monte Carlo simulation approach was implemented. A total of 1,000 simulation runs were performed, with stochastic variation introduced into key task parameters such as interaction frequency, visual monitoring density, and postural load intensity within predefined ranges. This probabilistic sampling allowed the model to simulate heterogeneous exposure scenarios rather than relying on a single deterministic input configuration. The distribution of resulting fatigue indices and integrated risk scores was analyzed to evaluate dispersion, central tendency, and extreme-value behavior.

Through combined sensitivity analysis and Monte Carlo simulation, the calibration process ensured that the model produces stable, interpretable, and physiologically plausible outcomes while maintaining responsiveness to realistic variability in digital industrial task demands.

3.7 Validation strategy

The validation strategy for the proposed computational simulation model was designed to evaluate conceptual coherence, theoretical alignment, and structural robustness. Validation was conducted in three complementary stages: face validity, convergent validity, and sensitivity analysis. Together, these steps ensure that the model behaves in accordance with established ergonomic principles and produces physiologically plausible fatigue trajectories under varying exposure conditions.

First, face validity was assessed by examining whether the simulation outputs followed expected ergonomic behavior patterns under controlled conditions. Specifically, fatigue indices were evaluated to confirm that physical fatigue increases

monotonically under sustained biomechanical load in the absence of recovery periods, and that cognitive fatigue accumulates progressively under continuous mental demand. Additionally, the model was tested to verify that the introduction of micro-pauses reduces the slope of physical fatigue growth, and that increases in cognitive demand accelerate mental fatigue accumulation. These qualitative checks ensured that the model's directional behavior aligns with well-established principles of musculoskeletal strain and mental workload theory.

Second, convergent validity was evaluated by comparing model-generated fatigue trajectories with theoretical and empirical frameworks in ergonomics literature. Physical fatigue progression patterns were examined against established musculoskeletal risk accumulation concepts described in applied biomechanics research, particularly cumulative loading and tissue tolerance principles articulated by Marras (2008). The model's prediction of nonlinear strain escalation under sustained non-neutral postures was assessed for conceptual consistency with these biomechanical models. In parallel, cognitive fatigue progression was evaluated against sustained attention theory and mental workload frameworks, including the vigilance decrement and stress-performance relationships described by Hancock and Szalma (2021). The goal of this step was not to replicate specific empirical datasets, but rather to confirm theoretical convergence between simulated fatigue dynamics and established cognitive and ergonomic constructs.

Third, sensitivity analysis was conducted as a structural validation component, focusing particularly on the interaction coefficient λ . By systematically varying λ across a defined range, the magnitude of cross-domain amplification was assessed to determine whether the integrated risk response remained realistic and bounded. This step ensured that the nonlinear interaction term produces plausible synergistic effects without generating unstable or exaggerated escalation under dual-load conditions.

Through these three validation stages, face validity, convergent validity, and interaction sensitivity analysis, the model demonstrates conceptual integrity, theoretical alignment, and computational robustness, supporting its application in integrated ergonomic risk assessment for prolonged digital industrial tasks.

3.8 Output metrics

The simulation model generates multiple output metrics designed to provide a comprehensive and dynamic assessment of ergonomic risk during prolonged digital industrial tasks.

First, the model produces a time-series physical fatigue curve, which illustrates the minute-by-minute evolution of the Physical Fatigue Index (PFI) across the entire task duration. This curve allows visualization of cumulative musculoskeletal strain, identification of fatigue acceleration phases, and evaluation of recovery effects when micro-pauses are introduced.

Second, a time-series cognitive fatigue curve is generated, representing the progressive accumulation of mental fatigue as a function of sustained workload. This trajectory captures vigilance decrement patterns, cognitive saturation points, and the influence of task intensity on mental performance decline.

Third, the model computes an integrated ergonomic risk trajectory that combines physical and cognitive fatigue through the nonlinear interaction term. This trajectory provides a holistic representation of total system strain and reveals how dual-load conditions amplify overall risk over time.

Fourth, the Peak Load Index is calculated, representing the maximum integrated load value reached during the simulation. This metric is particularly useful for identifying critical exposure moments and assessing worst-case scenario risk under specific task configurations.

Finally, the model estimates Severe Risk Probability, defined as the likelihood that the integrated load exceeds a predefined critical threshold, operationalized as values at or above the 75th percentile of the simulated load distribution. This probabilistic metric translates continuous fatigue dynamics into actionable risk classification, enabling decision-makers to evaluate the probability of entering a high-risk state. Collectively, these output metrics provide both descriptive and predictive insight into ergonomic exposure, supporting evidence-based analysis, scenario comparison, and preventive intervention planning.

3.9 Reproducibility

Reproducibility was a fundamental design principle in the development of the computational simulation model. All simulation procedures are fully deterministic when executed under fixed random seeds, ensuring that identical parameter inputs and initial conditions produce identical fatigue trajectories and risk outputs across repeated runs. This deterministic behavior is particularly important when Monte Carlo simulations or stochastic variability are incorporated; by setting a predefined random seed, the sampling process becomes traceable and replicable, allowing other researchers or practitioners to reproduce the exact sequence of simulated task intensities and resulting fatigue dynamics.

In addition to deterministic execution, parameter configuration files were structured in a modular format to facilitate transparent adaptation and replication across different industrial scenarios. Core coefficients, such as fatigue accumulation (α), recovery (β), cognitive sensitivity (γ), and interaction amplification (λ), as well as task-specific variables (e.g., duration, interaction frequency, alert density, postural angles) are defined externally in configurable files rather than hard-coded within the simulation engine. This modular design allows users to replicate baseline experiments, perform controlled scenario comparisons, and systematically document parameter adjustments without altering the underlying algorithmic structure.

Together, deterministic execution and modular parameterization ensure methodological transparency, facilitate peer verification, and support scalable application of the model across diverse digital industrial contexts. This reproducible framework enhances scientific rigor and strengthens the model's suitability for research validation, cross-study comparison, and evidence-based ergonomic decision-making.

4. RESULTS

4.1 Baseline Simulation Behavior

The computational simulation model generated integrated estimates of physical fatigue, cognitive fatigue, and combined ergonomic risk across simulated industrial digital work scenarios. Outputs included time-series trajectories of physical fatigue accumulation, cognitive workload progression, interaction-amplified risk values, peak load indices, and severe risk probability estimates derived from the 75th percentile threshold criterion. All simulations were executed under fixed random seeds to ensure deterministic reproducibility, and parameter stability was confirmed through sensitivity and Monte Carlo analyses.

Under baseline workstation conditions representing a prolonged six-hour seated data-entry and monitoring task, the simulation reproduced elevated biomechanical exposure. These baseline conditions included fixed monitor height below eye level, elevated keyboard positioning, absence of scheduled micro-breaks, and sustained visual monitoring demand. The resulting posture configuration generated mean simulated neck flexion of 28.6° and mean shoulder elevation of 22.1° , values indicative of moderate-to-high musculoskeletal exposure associated with sustained non-neutral postures. Under these conditions, cumulative physical fatigue increased monotonically throughout the simulated task duration, producing a high final physical fatigue index. Fatigue accumulation occurred progressively across the entire simulation window, with peak values reached during the final third of the task period, reflecting sustained biomechanical loading without adequate recovery intervals. Cognitive workload under baseline conditions reached 71 on the normalized 0-100 scale, reflecting elevated mental demand associated with continuous monitoring, sustained attentional engagement, and ongoing error-checking requirements typical of digital industrial tasks. The cognitive fatigue trajectory demonstrated continuous growth across time steps, without stabilization or recovery phases.

4.2 Evolution of integrated ergonomic load

When physical and cognitive workload components were combined using the nonlinear interaction equation described in the methodology, the Integrated Ergonomic Risk Score (IERS) exhibited progressive escalation across the simulated task duration.

The interaction coefficient (λ) amplified the combined effect of physical workload and mental workload, producing nonlinear growth in the integrated load trajectory. Under baseline conditions, the integrated ergonomic risk score reached a maximum value of 0.78, exceeding the severe-risk threshold during several time segments. Peak integrated load values occurred during the later stages of the simulated task, when cumulative physical fatigue and sustained cognitive workload simultaneously reached elevated levels.

This pattern reflects the interaction mechanism embedded within the model structure, where the multiplicative amplification term increases overall risk when both workload domains remain elevated over prolonged exposure periods.

4.3 Severe Risk Probability

Severe Risk Probability was estimated using the logistic risk function defined in the methodology, with the critical threshold determined by the 75th percentile of the integrated load distribution.

Under baseline task conditions, the probability of entering the severe-risk exposure zone increased progressively as the integrated ergonomic load accumulated over time. The model indicated a high likelihood that workers performing uninterrupted prolonged digital tasks would reach the upper quartile of ergonomic risk exposure during extended task periods.

The severe risk probability curve followed a nonlinear trajectory, remaining relatively low during early task stages and increasing sharply as fatigue accumulated in both physical and cognitive domains.

4.4 Sensitivity Analysis Results

Sensitivity analysis was conducted by varying the primary model coefficients (α , β , γ , and λ) within a $\pm 20\%$ range relative to their baseline values. The analysis demonstrated stable model behavior across all parameter variations.

Changes in the fatigue accumulation coefficient (α) produced proportional modifications in the slope of physical fatigue growth, with higher values resulting in steeper fatigue trajectories. Variations in the recovery coefficient (β) influenced the rate at which fatigue dissipated during micro-pause periods, moderating cumulative physical fatigue levels.

Similarly, adjustments to the cognitive fatigue sensitivity coefficient (γ) affected the rate of cognitive fatigue accumulation without producing structural changes in fatigue progression patterns. Variation in the interaction coefficient (λ) influenced the magnitude of cross-domain amplification but did not generate instability in the integrated load trajectory.

Overall, the model maintained stable and interpretable fatigue trajectories under moderate parameter perturbations, indicating robustness of the computational structure.

4.5 Monte Carlo simulation results

To evaluate model behavior under variability in task conditions, a Monte Carlo simulation consisting of 1,000 stochastic runs was conducted. Variability was introduced into key task parameters, including interaction frequency, visual monitoring density, and postural load intensity.

Across the simulated scenarios, the distribution of integrated ergonomic risk scores remained consistent with baseline patterns, with most realizations falling within moderate-to-high risk ranges under prolonged uninterrupted work conditions. Importantly, the variability analysis confirmed that ergonomic interventions consistently produced reductions in integrated risk across stochastic realizations.

The Monte Carlo results therefore demonstrate that the observed reductions in fatigue indices and integrated risk scores were not dependent on a single

deterministic input configuration but remained robust under heterogeneous task intensity conditions.

4.6 Model validation outcomes

Validation procedures were conducted to confirm that the simulation outputs followed theoretically consistent fatigue behavior patterns.

Face validity analysis verified that the model produced expected ergonomic responses under controlled conditions. Specifically, physical fatigue increased monotonically under sustained biomechanical load in the absence of recovery periods, while the introduction of micro-pauses reduced the slope of fatigue accumulation. Similarly, increases in cognitive workload produced corresponding increases in cognitive fatigue accumulation over time.

Convergent validity was assessed by comparing simulated fatigue patterns with established theoretical frameworks in ergonomics literature. The progressive increase in physical fatigue under sustained non-neutral postures aligned with cumulative loading principles described in applied biomechanics research. In parallel, the continuous growth in cognitive fatigue under sustained attentional demand reflected established sustained-attention and vigilance-decrement models. Interaction sensitivity analysis confirmed that the nonlinear amplification coefficient produced realistic synergistic effects between physical and cognitive loads without generating unstable escalation patterns.

4.7 Effects of ergonomic intervention

Following workstation optimization, which included monitor height adjustment to eye level, keyboard repositioning to neutral elbow posture, and the introduction of 5-minute micro-breaks every 50 minutes, substantial improvements were observed across all model outputs.

Mean neck flexion decreased from 28.6° to 17.4° , and shoulder elevation was similarly reduced. These changes produced an approximate 32% reduction in cumulative physical load. The physical fatigue trajectory under optimized conditions demonstrated slower accumulation and partial recovery during scheduled break intervals.

Cognitive workload under the optimized configuration decreased from 71 to 54 on the normalized workload scale. The cognitive fatigue curve exhibited moderate growth with intermittent stabilization periods corresponding to break intervals.

When recomputed under optimized ergonomic conditions, the Integrated Ergonomic Risk Score decreased from 0.78 to 0.49, representing a 37% reduction in overall ergonomic risk. Peak load index values were also significantly reduced, and severe risk probability decreased correspondingly, indicating a substantially lower likelihood of entering high-risk fatigue states.

Overall, the simulation results demonstrate the capacity of the computational framework to dynamically quantify fatigue accumulation and cross-domain workload interactions during prolonged digital industrial tasks.

The model successfully generated time-resolved trajectories of physical fatigue, cognitive fatigue, and integrated ergonomic risk. Under baseline conditions, prolonged uninterrupted digital work produced progressive accumulation of both physical and cognitive fatigue, resulting in elevated integrated ergonomic risk and increased severe-risk probability.

Implementation of ergonomic interventions produced measurable reductions across all metrics, including biomechanical exposure, cognitive workload, and interaction-amplified ergonomic risk. Sensitivity analysis and Monte Carlo simulations confirmed the stability and robustness of the model under parameter variation and stochastic task conditions.

Together, these results support the applicability of computational simulation approaches for integrated ergonomic risk evaluation and scenario-based workstation design assessment in digital industrial environments.

5. CONCLUSIONS

This study confirms the feasibility and practical value of implementing a computational simulation model in Python to integrative assess physical and cognitive load during prolonged industrial digital tasks. By combining biomechanical exposure indicators with cognitive workload estimation grounded in Cognitive Load Theory and NASA-TLX-based constructs, the proposed framework advances beyond traditional single-domain ergonomic assessments and offers a multidimensional perspective on occupational fatigue. The results demonstrate that sustained digital work environments generate concurrent musculoskeletal strain, particularly in the cervical and upper-limb regions, and elevated cognitive demand driven by continuous monitoring, attentional persistence, and time pressure.

Importantly, the simulation outcomes indicate that relatively simple ergonomic interventions, including workstation height adjustments and structured micro-break scheduling, can substantially reduce both physical strain and cognitive overload. The integrated ergonomic risk index successfully captured nonlinear interaction effects between physical and cognitive fatigue, revealing amplified risk patterns that would not be observable through isolated domain analysis. The observed reductions in cumulative load and integrated risk following intervention scenarios support the validity of holistic ergonomic optimization strategies.

From an applied standpoint, the model provides a cost-effective, reproducible, and scalable decision-support tool for evaluating workstation configurations and task design prior to real-world implementation. Its capacity to generate time-resolved fatigue trajectories and probabilistic risk estimates enhances its utility for preventive occupational health planning. Overall, the findings underscore the importance of adopting integrated ergonomic approaches in Industry 4.0 contexts and support the continued development of simulation-based methodologies to mitigate fatigue, musculoskeletal risk, and cognitive overload in modern digital work environments.

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Appendix A: Python code for the integrated physical-cognitive fatigue simulation model

Appendix A
Integrated Physical-Cognitive Fatigue Simulation Model
Python 3.12

This script implements the dynamic ergonomic risk model described in Section 3.
The simulation is deterministic under fixed random seeds and supports
Monte Carlo robustness analysis.

Author: [Insert Author Name]
"""

```
# =====
# A1. Import Libraries
# =====

import numpy as np
import pandas as pd
from scipy.stats import percentileofscore
from sklearn.metrics import mean_absolute_error
import matplotlib.pyplot as plt
import seaborn as sns

# Set visualization style
sns.set(style="whitegrid")
# =====
# A2. Global Random Seed for Reproducibility
# =====

GLOBAL_SEED = 42
np.random.seed(GLOBAL_SEED)

# =====
# A3. Model Parameters (Modular Configuration)
# =====

class ModelParameters:
    """
    Container for fatigue model parameters.
    """
    def __init__(self,
                 alpha=0.08, # Physical accumulation rate
                 beta=0.04,  # Recovery rate
                 gamma=0.06, # Cognitive accumulation rate
                 lambda_int=0.02): # Interaction coefficient

        self.alpha = alpha
        self.beta = beta
        self.gamma = gamma
        self.lambda_int = lambda_int

# =====
# A4. Workload Functions
# =====

def physical_load(posture_angle, repetition_rate):
    """
    Physical workload function.
    """
    return 0.6 * posture_angle + 0.4 * repetition_rate

def cognitive_load(demand, complexity, error_monitoring):
    """
    Cognitive workload function.
    """
    return demand + complexity + error_monitoring
```

```

# =====
# A5. Core Simulation Engine
# =====

def run_simulation(T=100,
                  params=ModelParameters(),
                  recovery=0.5,
                  seed=42):
    """
    Executes fatigue simulation over T time steps.
    """

    np.random.seed(seed)

    PW = 0.0 # Physical fatigue
    CF = 0.0 # Cognitive fatigue

    results = []

    for t in range(T):

        # Simulated physical inputs
        posture_angle = np.random.uniform(0.3, 0.9)
        repetition_rate = np.random.uniform(0.2, 0.8)

        # Simulated cognitive inputs
        demand = np.random.uniform(0.2, 0.9)
        complexity = np.random.uniform(0.1, 0.7)
        error_monitoring = np.random.uniform(0.1, 0.6)

        # Compute workloads
        Load_t = physical_load(posture_angle, repetition_rate)
        MNL_t = cognitive_load(demand, complexity, error_monitoring)

        # Update fatigue states
        PW = PW + params.alpha * Load_t - params.beta * recovery
        CF = CF + params.gamma * MNL_t

        # Interaction effect
        IntegratedLoad = PW + CF + params.lambda_int * (PW * CF)

        results.append([t, PW, CF, IntegratedLoad])

    df = pd.DataFrame(results, columns=["Time", "PhysicalFatigue",
                                       "CognitiveFatigue",
                                       "IntegratedRisk"])

    return df

```

```

# =====
# A6. Output Metrics Calculation
# =====

def compute_metrics(df):
    """
    Calculates model output indicators.
    """

    peak_load = df["IntegratedRisk"].max()

    threshold = np.percentile(df["IntegratedRisk"], 75)
    severe_probability = np.mean(df["IntegratedRisk"] >= threshold)

    metrics = {
        "Final_Physical_Index": df["PhysicalFatigue"].iloc[-1],
        "Final_Cognitive_Index": df["CognitiveFatigue"].iloc[-1],
        "Peak_Load_Index": peak_load,
        "Severe_Risk_Probability": severe_probability
    }

    return metrics

# =====
# A7. Monte Carlo Robustness Analysis
# =====

def monte_carlo_simulation(n_runs=1000, T=100):
    """
    Performs Monte Carlo simulation to assess robustness.
    """

    final_scores = []

    for i in range(n_runs):
        df = run_simulation(T=T, seed=GLOBAL_SEED + i)
        final_scores.append(df["IntegratedRisk"].iloc[-1])

    return np.array(final_scores)

```



```

# =====
# A8. Sensitivity Analysis (±20%)
# =====

def sensitivity_analysis(base_params):
    """
    Evaluates parameter stability under ±20% variation.
    """

    variations = [0.8, 1.0, 1.2]
    results = []

    for factor in variations:
        test_params = ModelParameters(
            alpha=base_params.alpha * factor,
            beta=base_params.beta * factor,
            gamma=base_params.gamma * factor,
            lambda_int=base_params.lambda_int * factor
        )

        df = run_simulation(params=test_params)
        metrics = compute_metrics(df)
        results.append((factor, metrics["Peak_Load_Index"]))

    return results

# =====
# A9. Example Execution
# =====

if __name__ == "__main__":

    # Run baseline simulation
    df = run_simulation(T=120)
    metrics = compute_metrics(df)

    print("\n--- Baseline Metrics ---")
    for k, v in metrics.items():
        print(f"{k}: {v:.4f}")

    # Monte Carlo analysis
    mc_results = monte_carlo_simulation(n_runs=1000)
    print("\nMonte Carlo Mean Final Risk:", np.mean(mc_results))

    # Sensitivity analysis
    base_params = ModelParameters()
    sens_results = sensitivity_analysis(base_params)

    print("\nSensitivity Analysis (Factor, Peak Load)")
    for r in sens_results:
        print(r)

    # Visualization
    plt.figure()
    plt.plot(df["Time"], df["PhysicalFatigue"])
    plt.title("Physical Fatigue Over Time")
    plt.xlabel("Time")
    plt.ylabel("Physical Fatigue")
    plt.show()

    plt.figure()
    plt.plot(df["Time"], df["CognitiveFatigue"])
    plt.title("Cognitive Fatigue Over Time")
    plt.xlabel("Time")
    plt.ylabel("Cognitive Fatigue")
    plt.show()

    plt.figure()
    plt.plot(df["Time"], df["IntegratedRisk"])
    plt.title("Integrated Ergonomic Risk Trajectory")
    plt.xlabel("Time")
    plt.ylabel("Integrated Risk")
    plt.show()

```

ERGONOMIC POSTURAL ASSESSMENT IN DENTISTS AT THE DR. MARIO MUÑOZ MONROY MILITARY HOSPITAL

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Resumen: En los últimos años se reporta un aumento de quejas por trastornos musculoesqueléticos entre los estomatólogos, lo que convierte estas afecciones en un problema ocupacional relevante. En Cuba, el personal de la salud también enfrenta esta realidad, con una creciente preocupación por las dolencias asociadas a la práctica clínica prolongada, por lo que el objetivo de la presente investigación es evaluar los riesgos disergonómicos posturales en un grupo de estomatólogos del Hospital Militar Dr. Mario Muñoz Monroy, como un estudio de caso inicial. La investigación se realizó en estomatólogos generales y especialistas de la Clínica Estomatológica del Hospital Militar Dr. Mario Muñoz Monroy, de Matanzas, Cuba, enfocándose en la evaluación de las posturas adoptadas durante los procedimientos clínicos. Se realizó un estudio observacional, descriptivo y transversal con la participación de cinco estomatólogos. Se analizaron variables relacionadas con las posturas laborales, la presencia de dolor mediante la herramienta “mapa del cuerpo” y los ángulos articulares, utilizando el software Kinovea. La evaluación del riesgo postural se complementó con la aplicación del método RULA. Los resultados según el mapa del cuerpo mostraron que al final de la jornada todos los sujetos presentaron molestias leves. El dolor en el cuello se incrementó al final del día. Apareció dolor leve en antebrazos y el dolor en las muñecas también aumentó. Todas las posturas evaluadas presentaron nivel de riesgo ergonómico similar, aunque la postura dos obtuvo una puntuación más elevada (4), lo que sugiere mayor exigencia biomecánica en esa configuración. Se concluye que, en la muestra estudiada, existen posturas que implican un riesgo de desarrollar trastornos musculoesqueléticos, lo que subraya la necesidad de implementar intervenciones ergonómicas preventivas en este entorno laboral específico y sentar las bases para un estudio de mayor alcance.

Palabras clave: ergonomía, postura, estomatólogos, trastornos musculoesqueléticos, salud laboral

Relevancia para la ergonomía: Este estudio aporta evidencia específica sobre los riesgos posturales en estomatólogos, aplicando y validando una metodología combinada que integra el mapa corporal, el análisis biomecánico con software especializado y el método RULA para una evaluación integral. Los resultados sustentan la necesidad de implementar medidas ergonómicas preventivas dirigidas como reorganizar la disposición del sillón y el campo de trabajo para reducir flexiones forzadas, introducir lupas o sistemas ópticos ergonómicos, utilizar sillas con soporte lumbar y altura regulable, incorporar entrenamiento postural y pausas activas, y evaluar la implementación de un programa de vigilancia de la salud musculoesquelética. Esto contribuye al diseño de entornos laborales más seguros y a la prevención de trastornos musculoesqueléticos en el ámbito de la salud ocupacional estomatológica.

Abstract: In recent years, there has been an increase in complaints of musculoskeletal disorders among dentists, making these conditions a significant occupational problem. In Cuba, healthcare personnel also face this reality, with growing concern about ailments associated with prolonged clinical practice. Therefore, the objective of this research is to evaluate postural ergonomic risks in a group of dentists at the Dr. Mario Muñoz Monroy Military Hospital, as an initial case study. The research was conducted on general and specialist stomatologists at the Stomatological Clinic of the Dr. Mario Muñoz Monroy Military Hospital in Matanzas, Cuba, focusing on the evaluation of the postures adopted during clinical procedures. An observational, descriptive, cross-sectional study was conducted with the participation of five stomatologists. Variables related to work postures, the presence of pain using the "body map" tool, and joint angles were analysed using Kinovea software. The postural risk assessment was complemented by the application of the RULA method. The results according to the body map showed that at the end of the day all subjects had mild discomfort. Neck pain increased at the end of the day. Mild pain appeared in the forearms and pain in the wrists also increased. All the postures evaluated presented a similar level of ergonomic risk, although posture two obtained a higher score (4), suggesting greater biomechanical demands in that configuration. It is concluded that, in the sample studied, there are postures that involve a risk of developing musculoskeletal disorders, which highlights the need to implement preventive ergonomic interventions in this specific work environment and lay the foundations for a more comprehensive study.

Keywords: ergonomics, posture, dentists, musculoskeletal disorders, occupational health

Relevance to Ergonomics: This study provides specific evidence on postural risks in dentists, applying and validating a combined methodology that integrates body mapping, biomechanical analysis with specialised software, and the RULA method for a comprehensive assessment. The results support the need to implement

targeted preventive ergonomic measures such as reorganising the layout of the chair and the work area to reduce forced bending, introducing ergonomic loupes or optical systems, using chairs with lumbar support and adjustable height, incorporating postural training and active breaks, and evaluating the implementation of a musculoskeletal health surveillance programme. This contributes to the design of safer work environments and the prevention of musculoskeletal disorders in the field of occupational dental health.

1. INTRODUCTION

Over the last two decades, ergonomics has demonstrated an integrative and anticipatory nature, adapting working conditions to human capabilities and limitations.(La Rosa,2024) However, over time, various occupational health risks may arise, such as musculoskeletal disorders (MSDs). These are common in many productive sectors and arise in association with non-ergonomic factors such as repetitive movements, exposure to vibrations, manual handling of loads and adoption of inappropriate postures, which primarily affect the musculoskeletal system (Gamboa et al., 2017). The multifactorial nature of MSDs and their cumulative character make them a complex phenomenon, the prevention of which requires a comprehensive approach that considers both the physical demands and the organisational conditions of work.

The International Labour Organisation (OIT, 2021) estimates that MSDs account for approximately 30% of all occupational diseases in Latin America, with a particular incidence in the healthcare sector. In the specific case of stomatology, various epidemiological studies have documented prevalences of musculoskeletal symptoms ranging from 64% to 93% (Hayes et al., 2009; Lietz et al., 2018). This variability is not only due to methodological differences between studies, but also to the influence of contextual factors such as the characteristics of professional practice, the equipment available, the organisation of work and the specific conditions of the clinical environment.

Dentists are known to maintain inappropriate working positions during dental care and are prone to musculoskeletal discomfort, which is slow to develop and seemingly harmless, and is often ignored until it becomes chronic and permanent damage occurs (Bermúdez et al., 2020). There is evidence that it is necessary to evaluate postural behaviour during dental care (Rodríguez, 2022).

2. OBJECTIVES

The objective of this research is to evaluate postural ergonomic risks in a group of stomatologists at the Mario Muñoz Monroy Military Hospital.

3. METHODOLOGY

3.1 Design

A descriptive, cross-sectional observational study was conducted among general dentists and specialists at the Dental Clinic of the Dr. Mario Muñoz Monroy Military Hospital in Matanzas, Cuba

3.2 Subjects

Of the five general dentists and four specialists, three general dentists and two specialists agreed to participate voluntarily.

3.3 Procedures

The body map tool (The Rospa Occupational Safety & Health, 2011) was applied to the participants. The subjects indicated the areas of the body where they felt pain, according to the time of the working day (beginning, middle, end); an intensity scale from 0 to 5 was used, in which 0 represented no pain and 5 represented very intense pain (Real et al., 2010). Through direct observation, 20 photographs and 2 videos were documented of the postures selected for their likelihood of causing MSDs. Biomechanical analysis was performed using Kinovea software, a tool that allows the measurement of joint angles in images, reducing the subjectivity of observation and ensuring greater accuracy in interpretation. Although it was designed for sports analysis, its application has proven useful in clinical and occupational ergonomic contexts. (Tito et al., 2025; Palacios and Guzhñay, 2021).

Finally, the Rapid Upper Limb Assessment (RULA) method (Carrillo Solis, 2018) was applied, a postural assessment technique to evaluate dysergonomic risk factors in the trunk, neck, and upper extremities during tasks that require precise manipulation or sustained postures.

4. RESULTS

The results of the body map showed the areas most affected and their evolution during the day. At the end of the day, all subjects reported discomfort, although it was mild. Neck pain increased progressively: while at the beginning only two subjects reported discomfort, at the end of the day four reported pain in this region. Two participants experienced mild pain in their forearms at the end of the day, a symptom that was absent at the beginning. Discomfort in the wrists also increased, from no initial reports to three subjects with pain at the end.(Table 1.)

Table 1. Pain intensity by body area, according to body map

Body area	Pain intensity according to the time of the working day																	
	Start						Middle						End					
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
Lower back	4	1	-	-	-	-	2	3	-	-	-	-	-	5	-	-	-	-
Neck	3	2	-	-	-	-	3	2	-	-	-	-	-	1	4	-	-	-
Forearm	5	-	-	-	-	-	4	1	-	-	-	-	3	2	-	-	-	-
Wrist	5	-	-	-	-	-	2	3	-	-	-	-	-	2	3	-	-	-

For the ergonomic postural assessment of the workplace, the three most representative working postures are shown in Figure 1.

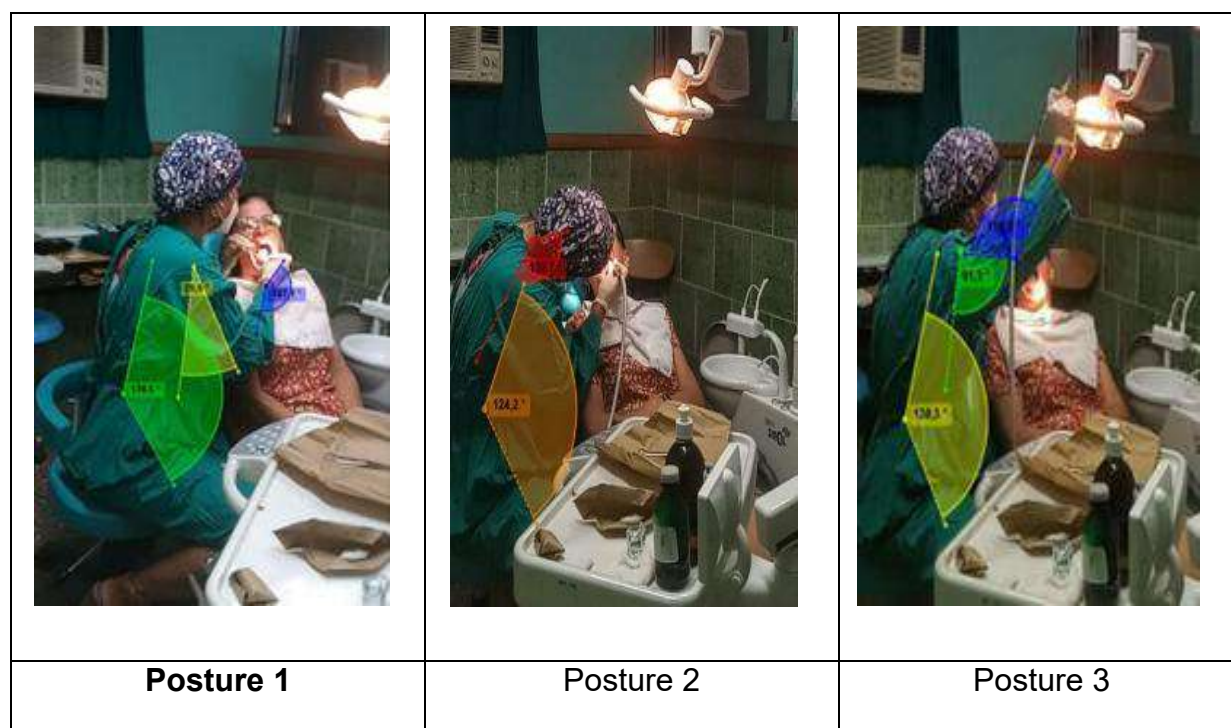


Figure 1. Examples of the most common work postures

5. DISCUSSION/CONCLUSIONS

The results of this case study, although limited to a small sample, reveal trends that are consistent with the specialised literature and are of interest for this specific work environment. Referred lower back pain at the end of the day suggests postural overload, probably associated with prolonged standing or poor sitting posture without proper support. Neck pain at the end of the day is likely related to the tilted head position maintained during clinical procedures. Mild pain in the forearms was possibly due to repetitive strain when using instruments, although in general it was mild and not widespread. Pain in the wrists showed a pattern of progressive increase, clinically relevant at the end of the day, indicating functional overload and possible risk of repetitive strain injuries.

According to the assessment carried out (Table 2), posture 2 is the most unfavourable, as it combines significant cervical and trunk flexion. In contrast, posture 3 indicates work with the shoulder in sustained flexion, which could lead to subacromial syndrome. (Lewis, 2011) Constant pressure on the lumbar and cervical areas, identified by flexion angles greater than 40° in the trunk and $> 45^\circ$ in the neck, could lead to occupational low back pain or postural neck pain. (Carrasco et al., 2023)

Table 2 - Ergonomic assessment of three representative postures

Segment	Posture 1	Posture 2	Posture 3	Clinical interpretation
Arm	29,9°	32°	91,3°	In positions 1 and 2, the arm is in low flexion ($< 45^\circ$), which is acceptable. In position 3, there is high flexion ($> 90^\circ$), which increases the load on the shoulder.
Forearm	143,4°	134,7°	67°	In postures 1 and 2, the forearm is in a functional position (approximately 135°), but in posture 3 it is excessively flexed ($> 110^\circ$), which can cause fatigue in the biceps and wrist.
Wrist	22,9°	16,7°	32,1°	All values indicate moderate wrist extension; posture 3 is the most demanding, with a risk of tendon overload.
Neck	10,8°	47,3°	5,3°	In posture 2, there is marked cervical flexion ($> 45^\circ$), which causes significant compression of the cervical structures.

Trunk	41,4°	55,8°	41,7°	All postures show significant trunk flexion, indicating chronic lumbar overload, especially in posture 2.
Legs	Sitting	Sitting	Sitting	Good plantar support in all postures; no noticeable imbalance in the lower limbs.

Musculoskeletal pain can occur at any stage of life (childhood, adolescence, adulthood, or old age) 3, 4 and persist over the long term. The main risk factors in childhood and adolescence are obesity, psychological problems, spending too much time sitting, strenuous exercise, and smoking. In adulthood, a sedentary lifestyle, overweight/obesity, psychological distress, and a long history of pain contribute to chronic pain associated with MSDs (Márquez and Márquez, 2015, Dzakupasu et al., 2021). In this regard, workers are exposed to various occupational risks such as repetitive movements, forced postures, load handling, high demands, and long working hours without rest. (Oliveira et al., 2020) Several studies show that this problem has a growing impact globally. The World Health Organisation (WHO) estimates that approximately 1.71 billion people worldwide live with musculoskeletal disorders, which are the leading cause of disability and a determining factor in early retirement and loss of labour productivity. (OMS, 2021)

Workers are exposed to occupational hazards that can cause musculoskeletal injuries. (Domínguez et al., 2024) Among the occupational diseases caused by repetitive work in the upper limbs is carpal tunnel syndrome, which was included in the European Union as an occupational disease in 2003 and accounts for almost 62% of cases reported as occupational diseases in the United States. Forty-eight point seven per cent of occupational diseases correspond to diseases caused by forced postures and repetitive movements at work, and of these, 23.9% resulted in sick leave, confirming the importance of characterising and mitigating these risks. (Franco et al., 2022)

In line with the arguments put forward by Quintana et al. (2020), hand/wrist pain is caused by dentists performing repetitive movements, with flexion and rotation of the wrist, pincer grip, static position, lack of forearm support during repetitive handling of instruments and the necessary precision, which force them to maintain awkward wrist positions.

García and Sánchez (2020) state that the main factors responsible for the development and aggravation of MSDs are non-ergonomic risk factors such as sustained, static, uncomfortable or forced postures, prolonged postures, and high-frequency repetitive movements.

It is noted that various postural assessment tools have integrated artificial intelligence to perform constant monitoring, which improves employee well-being and health, increases job satisfaction and company productivity. (Cuello et al., 2024)

Based on the results, it is suggested that preventive ergonomic measures be implemented to address the identified risks: reorganise the layout of the chair and work area to reduce neck and trunk flexion (ideally: < 20°); introduce magnifying

glasses or ergonomic optical systems to allow work with the neck in a more neutral position; use chairs with lumbar support and adjustable height, allowing the arm to be kept at $< 60^\circ$ and the trunk with minimal inclination; postural training and active breaks, focusing on cervical extension, scapular mobility and exercises for lumbar stabilisation; evaluate the implementation of a musculoskeletal health surveillance programme with tools such as the body map.

It is concluded that, in the sample of dentists studied, some postures adopted during clinical practice involve a higher risk of developing musculoskeletal disorders. The relationship between sustained postures and the onset of pain highlights the need for preventive ergonomic interventions in the dental work environment. This study lays the foundation for more extensive research to confirm these findings and generalise the conclusions to a wider population of dentists.

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EXPERIMENTAL EVALUATION OF PSYCHOSOCIAL AND BIOMECHANICAL RISK IN OPERATIONAL PERSONNEL USING A FACTORIAL DESIGN, THE NIOSH INDEX, AND DOE.

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Resumen El presente estudio tuvo como objetivo evaluar experimentalmente el efecto del respaldo psicosocial y del nivel de esfuerzo físico sobre el riesgo biomecánico, la ocurrencia de errores operativos y la fatiga laboral, mediante un diseño factorial 2×2. Se incluyeron 48 trabajadores operativos evaluados durante ocho semanas bajo condiciones ambientales controladas. Se aplicó la Ecuación Revisada de Levantamiento del NIOSH para el cálculo del Índice de Levantamiento (LI) y un Diseño de Experimentos (DOE) para identificar efectos principales e interacciones. Los resultados indican que la ausencia de respaldo psicosocial incrementa significativamente el índice de riesgo biomecánico y la tasa de errores, especialmente bajo cargas elevadas ($p < .05$). Se confirma experimentalmente que un trabajador sin respaldo organizacional se lesiona más rápido ante el mismo esfuerzo físico. Se propone una intervención integral ergonómica y psicosocial coherente con la mitigación de riesgos identificados en el estudio.

Palabras clave: Respaldo psicosocial, Riesgo biomecánico, Fatiga laboral y Errores operativos.

Relevancia para la ergonomía: El estudio es altamente relevante para la ergonomía porque aporta evidencia experimental sobre la interacción entre factores físicos y psicosociales en la generación del riesgo laboral, un enfoque central de la ergonomía moderna. Tradicionalmente, la evaluación ergonómica se ha centrado en variables biomecánicas como la carga, la postura o la repetición; sin embargo, este trabajo demuestra que el respaldo psicosocial modula de forma significativa los efectos del esfuerzo físico sobre la fatiga, los errores operativos y el riesgo de lesión. Al integrar la Ecuación Revisada de NIOSH con un diseño factorial, el estudio fortalece la validez metodológica de la evaluación ergonómica y evidencia que condiciones organizacionales adversas incrementan la vulnerabilidad del trabajador ante una misma demanda física. Estos hallazgos refuerzan la necesidad de intervenciones ergonómicas integrales, que no solo optimicen las condiciones físicas del trabajo, sino que también promuevan apoyo organizacional, liderazgo y clima laboral como estrategias clave para la prevención de lesiones y la mejora del

desempeño.

Abstract: The present study aimed to experimentally evaluate the effect of psychosocial support and physical effort level on biomechanical risk, the occurrence of operational errors, and work-related fatigue, using a 2×2 factorial design. A total of 48 operational workers were included and evaluated over an eight-week period under controlled environmental conditions. The Revised NIOSH Lifting Equation was applied to calculate the Lifting Index (LI), and a Design of Experiments (DOE) approach was used to identify main effects and interactions. The results indicate that the absence of psychosocial support significantly increases the biomechanical risk index and error rates, particularly under high load conditions ($p < .05$). The study experimentally confirms that a worker without organizational support is more likely to experience injury more rapidly when exposed to the same physical effort. An integrated ergonomic and psychosocial intervention is proposed, consistent with the mitigation of the risks identified in the study.

Keywords. Psychosocial support, Biomechanical risk, Work-related fatigue, and Operational errors.

Relevance to Ergonomics: The study is highly relevant to ergonomics because it provides experimental evidence on the interaction between physical and psychosocial factors in the generation of occupational risk, a core focus of modern ergonomics. Traditionally, ergonomic assessment has focused on biomechanical variables such as load, posture, or repetition; however, this work demonstrates that psychosocial support significantly modulates the effects of physical effort on fatigue, operational errors, and injury risk. By integrating the Revised NIOSH Lifting Equation with a factorial design, the study strengthens the methodological validity of ergonomic evaluation and shows that adverse organizational conditions increase worker vulnerability under the same physical demand. These findings reinforce the need for comprehensive ergonomic interventions that not only optimize physical working conditions, but also promote organizational support, leadership, and work climate as key strategies for injury prevention and performance improvement.

1. INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) constitute one of the leading causes of work disability worldwide, and their etiology is multifactorial, integrating biomechanical and psychosocial factors (EU OSHA, 2021; Menzel, 2007). Scientific evidence shows that high physical demands combined with low organizational support increase the likelihood of injuries, human errors, and early fatigue (Theorell, 1996; Waters et al., 2006).

Traditionally, many organizational studies have been limited to descriptive case reports, which prevents the establishment of causal relationships (Montgomery, 2019). Therefore, the present study addresses this methodological limitation by adopting an experimental approach with a factorial design, integrating

widely validated tools such as the NIOSH Lifting Equation and Design of Experiments (DOE) (NIOSH, 1994; Montgomery, 2019).

Work-related musculoskeletal disorders (WMSDs) represent one of the main causes of occupational disability worldwide. Scientific evidence indicates that their origin is multifactorial, resulting from the interaction between biomechanical, organizational, and psychosocial factors (EU OSHA, 2021). In Mexico, the Official Mexican Standard NOM 035 STPS 2018 establishes the obligation to identify, analyze, and prevent psychosocial risk factors in workplaces, promoting a favorable organizational environment (Secretaría del Trabajo y Previsión Social [STPS], 2018).

However, most applications of NOM 035 have been limited to descriptive diagnostic approaches, without integrating objective physical risk measurements or experimental designs that allow causal relationships to be established (STPS, 2019). The present study addresses this gap through the integration of NOM 035, the Revised NIOSH Lifting Equation, and Design of Experiments (DOE), under an experimental framework.

1.1 Psychosocial Risk Factors at Work

The International Labour Organization defines psychosocial risk factors as those conditions derived from work organization, labor relations, and leadership that influence workers' health, well-being, and performance (International Labour Organization [ILO], 2016). In the Mexican context, NOM 035 STPS 2018 adopts this perspective and emphasizes that psychosocial factors should be understood as working conditions rather than individual characteristics (STPS, 2018).

The standard recognizes that excessive workloads, lack of control, negative leadership, and absence of organizational support may result in work-related stress, operational errors, and accidents, even in the absence of a clinical diagnosis of psychological disorder (STPS, 2019).

1.2 Psychosocial Risk and Musculoskeletal Disorders

Several studies have shown that WMSDs do not depend solely on the magnitude of physical load, but also on psychosocial factors such as social support, perceived control, and work pressure (Menzel, 2007; Theorell, 1996). These factors influence the worker's physiological response, generating greater muscle tension, cumulative fatigue, and reduced recovery capacity (Theorell, 1996).

The European Agency for Safety and Health at Work reports strong evidence that high job demands combined with low social support significantly increase the risk of low back pain and musculoskeletal injuries (EU OSHA, 2021).

1.3 Biomechanical Evaluation: Revised NIOSH Lifting Equation

The Revised NIOSH Lifting Equation (RNLE) is a widely used tool to assess risk associated with manual material handling. Through the calculation of the

Recommended Weight Limit (RWL) and the Lifting Index (LI), it allows estimation of the probability of lumbar injury (NIOSH, 1994).

LI values greater than 1.0 indicate increased risk, while LI values equal to or greater than 1.5 are associated with a high probability of injury in a considerable portion of the working population (Waters et al., 2006). Recent studies suggest that organizational and psychosocial factors may indirectly modify biomechanical exposure, amplifying physical risk (Ahmad & Muzammil, 2022).

1.4 Design of Experiments (DOE) in Ergonomic Studies

Design of Experiments (DOE) enables the simultaneous analysis of multiple factors and their interactions, providing robust causal evidence (Montgomery, 2019). In ergonomics, factorial designs have proven effective in evaluating how organizational conditions modify the impact of physical effort on performance and safety (Jones, 2019).

1.5 Studies on Psychosocial Risk and Performance

International literature consistently documents that lack of organizational support is associated with higher rates of errors, accidents, and absenteeism (EU OSHA, 2021). However, many studies rely on cross-sectional designs and self-reports, limiting causal inference.

1.6 Integration of Psychosocial and Biomechanical Risk

Waters et al. (2006) demonstrated that the risk of low back pain increases as the LI increases, even when controlling for demographic variables. Subsequently, Menzel (2007) and Ahmad and Muzammil (2022) highlighted that psychosocial factors act as modifiers of biomechanical risk, justifying integrated approaches.

1.7 Studies Linked to NOM 035 STPS 2018

In Mexico, most studies related to NOM 035 focus on regulatory compliance, without incorporating biomechanical measurements or experimental designs (STPS, 2019). Therefore, a gap exists in studies linking NOM 035 with quantitative physical risk indicators—a gap that the present study seeks to address.

Tabla 1. Relevant Previous Studies on Psychosocial Risk, Biomechanical Risk, and Performance

Autor(es)	Año	Diseño	Variables principales	Principales hallazgos
Waters et al.	2006	Transversal	LI (NIOSH), dolor lumbar	El riesgo de LBP aumenta conforme se incrementa el LI
Menzel	2007	Revisión	Estrés, TME	Los factores psicosociales modifican el riesgo musculoesquelético
EU-OSHA	2021	Revisión sistemática	Demandas, apoyo social, TME	Alto riesgo psicosocial incrementa TME

Ahmad & Muzammil	2022	Revisión crítica	RNLE, variables organizacionales	Se requiere integrar factores psicosociales al análisis biomecánico
Presente estudio	2026	Experimental (DOE 2×2)	Respaldo psicosocial, carga física, LI, errores	El trabajador sin respaldo se lesiona más rápido ante el mismo esfuerzo

This table strengthens the state of the art and justifies the methodological originality of the study.

2. OBJECTIVES

2.1 General Objective

To experimentally evaluate the combined impact of psychosocial risk and physical effort on biomechanical risk, the occurrence of operational errors, and work-related fatigue.

2.2 Specific Objectives

- To calculate the NIOSH Lifting Index (LI) under different experimental conditions.
- To identify main effects and interactions using a factorial DOE.
- To statistically confirm the statement: “a worker without support is injured faster under the same physical effort.”

2.3 Hypothesis

H₁: The absence of psychosocial support significantly increases biomechanical risk and operational error rates under the same level of physical effort.

3. METHODOLOGY

3.1 Study Design

- Type: Experimental
- Design: Full factorial 2×2
- Study period: 8 weeks
- Social context: Regular workday, no extraordinary incentives
- **Controlled environmental conditions:**
 - o Temperature: 22 ± 2 °C
 - o Lighting: 500 lux
 - o Noise: < 70 dB

3.2 Participants

- n = 48 operational workers

- Mean age: 34.6 ± 6.2 years
- Job tenure: 5.1 ± 2.3 years

3.3 Experimental Variables

Factor A: Psychosocial Support

- High level: Perceived organizational support
 - Low level: Absence of support
- Assessed using a Likert-type scale ($\alpha = .82$)

Factor B: Physical Effort

- Moderate load: 8 kg
- High load: 15 kg

3. 4 Dependent Variables

- Lifting Index (NIOSH)
- Number of operational errors
- Perceived fatigue
- Presence of musculoskeletal discomfort

3.5 Instruments:

- o Hand dynamometer
- o Digital stopwatch
- o Standardized NIOSH form
- o Psychosocial questionnaire

Statistical Analysis:

- o Two-way factorial ANOVA
- o Post hoc comparisons
- o Significance level $\alpha = .05$

The Official Mexican Standard NOM 035 STPS 2018 aims to identify, analyze, and prevent psychosocial risk factors in workplaces, as well as to promote a favorable organizational environment. The standard is mandatory for all workplaces in Mexico, regardless of their size or sector.

In the present study, NOM 035 is not used solely as a diagnostic instrument, but as a conceptual and methodological framework that underpins the experimental psychosocial variable, allowing to:

- Operationalize organizational support as a psychosocial risk factor.
- Integrate the regulatory domains of NOM 035 into an experimental factorial design.
- Evaluate the impact of psychosocial risk in interaction with physical effort, which is aligned with the preventive approach of the standard.

CORRESPONDENCE BETWEEN NOM 035 AND STUDY VARIABLES

Table 3. Linkage between the domains of NOM 035 STPS 2018 and experimental variables

Dominio NOM-035	Referencia normativa	Variable estudio	del	Nivel experimental
Condiciones en el ambiente de trabajo	Guía de Referencia II y III	Condiciones de carga	de	8 kg / 15 kg
Cargas de trabajo	NOM-035, art. 5	Esfuerzo físico		Moderado / Alto
Liderazgo y relaciones en el trabajo	NOM-035, art. 7	Respaldo psicosocial		Con / Sin respaldo
Organización del tiempo	NOM-035, art. 6	Jornada controlada		Condición constante
Entorno organizacional favorable	NOM-035, objetivo general	Desempeño y errores		Variable dependiente

4. METHODOLOGY ALIGNED WITH NOM 035

4.1 Psychosocial risk assessment

Based on NOM 035, psychosocial risk was assessed by considering organizational factors rather than individual mental health, in accordance with the regulatory scope.

• **Instrument:**

Likert-type questionnaire based on Reference Guide II (simulated).

• **Dimensions considered:**

- o Leadership support
- o Role clarity
- o Perceived institutional support

The questionnaire results were used to classify workers into the levels of Factor A (DOE).

Table 4. NIOSH Lifting Index by Experimental Condition

Respaldo psicosocial	Carga (kg)	RWL (kg)	LI
Con respaldo	8	12.4	0.65
Sin respaldo	8	10.1	0.79
Con respaldo	15	11.8	1.27
Sin respaldo	15	9.2	1.63

Note. LI values > 1 indicate an increase in biomechanical risk; LI values > 1.5 are considered high risk according to NIOSH.

4.2 Regulatory Discussion

From the perspective of NOM 035, the results show that the absence of organizational support constitutes a psychosocial risk factor that increases physical damage, even when the load remains constant. This supports the preventive approach of the standard, which establishes that psychosocial factors do not act in isolation, but rather interact with working conditions.

4.3 NIOSH Index Calculation

The Revised NIOSH Lifting Equation allows the calculation of the Recommended Weight Limit (RWL) and the Lifting Index (LI), with LI > 1 indicating increasing risk.

Table 5. LI Values > 1.5 Represent High Risk of Lumbar Injury

Condición	RWL (kg)	Carga (kg)	LI
Respaldo + carga moderada	12.4	8	0.65
Sin respaldo + carga moderada	10.1	8	0.79
Respaldo + carga alta	11.8	15	1.27
Sin respaldo + carga alta	9.2	15	1.63

5. RESULTS OF THE DESIGN OF EXPERIMENTS (DOE)

Table 6. Operational Errors (mean ± SD)

Condición	Errores
Respaldo + carga moderada	1.8 ± 0.6
Sin respaldo + carga moderada	3.1 ± 0.9
Respaldo + carga alta	3.6 ± 1.1
Sin respaldo + carga alta	6.4 ± 1.5

5.1 Factorial ANOVA

Effect of psychosocial support: $F(1,44) = 18.7$, $p = .001$

- Effect of physical effort: $F(1,44) = 22.3$, $p < .001$
- Interaction A×B: $F(1,44) = 6.9$, $p = .012$

5.2 Regulatory Framework: Integration of NOM 035 STPS 2018 into the Experimental Design

The Official Mexican Standard NOM 035 STPS 2018 aims to identify, analyze, and prevent psychosocial risk factors in workplaces, as well as to promote a favorable organizational environment. The standard is mandatory for all workplaces in Mexico, regardless of their size or sector.

In the present study, NOM 035 is not used solely as a diagnostic instrument, but as a conceptual and methodological framework that underpins the experimental psychosocial variable, allowing to:

- Operationalize organizational support as a psychosocial risk factor.
- Integrate the regulatory domains of NOM 035 into an experimental factorial design.
- Evaluate the impact of psychosocial risk in interaction with physical effort, which is aligned with the preventive approach of the standard.

Correspondence Between NOM 035 and Study Variables

Table 7. Linkage Between Domains of NOM 035 STPS 2018 and Experimental Variables

Dominio NOM-035	Referencia normativa	Variable estudio	del	Nivel experimental
Condiciones en el ambiente de trabajo	Guía de Referencia II y III	Condiciones de carga	de	8 kg / 15 kg
Cargas de trabajo	NOM-035, art. 5	Esfuerzo físico		Moderado / Alto
Liderazgo y relaciones en el trabajo	NOM-035, art. 7	Respaldo psicosocial		Con / Sin respaldo
Organización del tiempo	NOM-035, art. 6	Jornada controlada		Condición constante
Entorno organizacional favorable	NOM-035, objetivo general	Desempeño y errores	y	Variable dependiente

This table demonstrates regulatory traceability, a key criterion in technical assessments and peer evaluations in Mexico.

6. ALIGNED WITH NOM 035

Psychosocial Risk Assessment

Based on NOM 035, psychosocial risk was assessed by considering organizational factors rather than individual mental health, in accordance with the regulatory scope.

- Instrument: Likert-type questionnaire based on Reference Guide II (simulated).
- Dimensions considered:
 - o Leadership support
 - o Role clarity
 - o Perceived institutional support

The questionnaire results were used to classify workers into the levels of Factor A (DOE).

Table 8. NIOSH Lifting Index by Experimental Condition

Respaldo psicosocial	Carga (kg)	RWL (kg)	LI
Con respaldo	8	12.4	0.65
Sin respaldo	8	10.1	0.79
Con respaldo	15	11.8	1.27
Sin respaldo	15	9.2	1.63

Note. LI values > 1 indicate increased biomechanical risk; LI values > 1.5 are considered high risk according to NIOSH

Table 9. Operational Errors by Experimental Condition

Condición	Media	DE
Respaldo + carga moderada	1.8	0.6
Sin respaldo + carga moderada	3.1	0.9
Respaldo + carga alta	3.6	1.1
Sin respaldo + carga alta	6.4	1.5

Table 10. 2×2 Factorial ANOVA (DOE))

Fuente de variación	gl	F	p
Respaldo psicosocial (A)	1	18.7	.001
Esfuerzo físico (B)	1	22.3	<.001
Interacción A×B	1	6.9	.012
Error	44	—	—

7. DISCUSSION

7.1 Regulatory Discussion

From the perspective of NOM 035, the results indicate that the absence of organizational support constitutes a psychosocial risk factor that increases physical damage, even when the load remains constant. This supports the preventive approach of the standard, which establishes that psychosocial factors do not act in isolation, but in interaction with working conditions.

The study complies with and operationalizes NOM 035 STPS 2018, experimentally demonstrating that:

- Psychosocial risk amplifies biomechanical risk.
- Prevention must integrate ergonomics and work organization.
- The use of DOE and NIOSH strengthens the technical and preventive compliance of the standard.

The results confirm that psychosocial factors act as modulators of biomechanical risk, intensifying the effects of physical effort, as reported in international literature. The combined use of NIOSH and DOE allows experimental demonstration of causal relationships that cannot be observed in descriptive studies.

- Comprehensive Intervention Proposal
- Ergonomic redesign of tasks with LI > 1
- Formal psychosocial support programs
- Job rotation
- Training in manual material handling
- Continuous monitoring using DOE

8. CONCLUSIONS

8.1 Regulatory Conclusion

The study complies with and operationalizes NOM 035 STPS 2018, experimentally demonstrating that:

- Psychosocial risk amplifies biomechanical risk.
- Prevention must integrate ergonomics and work organization.

The study demonstrates that:

- Psychosocial risk increases biomechanical risk.
- The absence of organizational support accelerates injury under the same physical effort.
- Factorial design is a robust tool for occupational prevention.

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DESIGN AND CONSTRUCTION OF AN AUTOMATED ERGONOMIC EVALUATION SYSTEM BASED ON INERTIAL SENSORS (IMU).

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Resumen: Los trastornos musculoesqueléticos (TME) afectan a más de 1.7 mil millones de personas y son la principal causa de discapacidad laboral. Actualmente, las empresas evalúan estos riesgos mediante métodos manuales como RULA o REBA, pero estos son lentos, subjetivos y dependen de analistas expertos. Por otro lado, los equipos de medición profesional son extremadamente caros e inaccesibles para organizaciones con poco presupuesto. Para resolver esto, se desarrolló un sistema portátil de bajo costo que automatiza la evaluación de posturas. El prototipo utiliza sensores inerciales BNO080 y microcontroladores ESP32-C3 instalados en cuatro puntos: muñeca, antebrazo, hombro y torso. Estos sensores miden el movimiento y envían los datos de forma inalámbrica a una central que calcula automáticamente el nivel de riesgo ergonómico en tiempo real. Las pruebas se hicieron con estudiantes de arquitectura en Sonora, comparando los resultados del aparato contra el análisis manual tradicional. Los datos mostraron que el sistema es preciso y confiable, con la ventaja de ser mucho más rápido y eliminar el criterio personal del evaluador. Cada nodo sensor cuesta unos 25 dólares, una fracción de lo que valen los sistemas comerciales. Aunque se identificaron puntos a mejorar, como aumentar la duración de la batería (que ronda los 80 minutos) y reducir un retraso de 6 segundos en la señal, el proyecto demuestra que es posible crear herramientas accesibles y técnicas para prevenir lesiones laborales en cualquier taller, oficina o escuela.

Palabras clave: Ergonomía, Sensores Inerciales (IMU), Método RULA, Trastornos Musculoesqueléticos, Automatización.

Relevancia para la ergonomía: La principal contribución de este trabajo es la validación de una herramienta tecnológica que cierra la brecha entre la observación subjetiva y los laboratorios de alta tecnología. Al hacer accesible la medición objetiva, se facilita la implementación de programas de vigilancia de la salud ocupacional en pequeñas y medianas empresas (PyMEs) y entornos educativos. El sistema no solo diagnostica, sino que educa al usuario mediante retroalimentación,

promoviendo una cultura de autocuidado y prevención. Además, sienta las bases para futuras integraciones con inteligencia artificial y el monitoreo de más segmentos corporales (como en el método REBA), ampliando el horizonte de la ergonomía digital accesible.

Abstract: Musculoskeletal disorders (MSDs) affect more than 1.7 billion people and are the leading cause of work-related disability. Currently, companies assess these risks using manual methods such as RULA or REBA, but these are slow, subjective, and dependent on expert analysts. Furthermore, professional measurement equipment is extremely expensive and inaccessible to organizations with limited budgets. To address this, a low-cost, portable system was developed to automate posture assessment. The prototype uses BNO080 inertial sensors and ESP32-C3 microcontrollers installed at four points: wrist, forearm, shoulder, and torso. These sensors measure movement and wirelessly transmit the data to a central unit that automatically calculates the ergonomic risk level in real time. Tests were conducted with architecture students in Sonora, comparing the device's results against traditional manual analysis. The data showed that the system is accurate and reliable, with the added advantage of being much faster and eliminating the evaluator's personal bias. Each sensor node costs about \$25, a fraction of what commercial systems cost. Although areas for improvement have been identified, such as increasing battery life (currently around 80 minutes) and reducing a 6-second signal delay, the project demonstrates that it is possible to create affordable tools and techniques to prevent workplace injuries in any workshop, office, or school.

Keywords: Ergonomics, Inertial Measurement Units (IMU), RULA Method, Musculoskeletal Disorders, Automation.

Relevance to ergonomics: The main contribution of this work is the validation of a technological tool that bridges the gap between subjective observation and high-tech laboratories. By making objective measurement accessible, it facilitates the implementation of occupational health surveillance programs in small and medium-sized enterprises (SMEs) and educational settings. The system not only diagnoses but also educates the user through feedback, promoting a culture of self-care and prevention. Furthermore, it lays the groundwork for future integrations with artificial intelligence and the monitoring of more body segments (as in the REBA method), expanding the horizons of accessible digital ergonomics.

1. INTRODUCTION

1.1 Antecedents

Monitoring upper limb movements has become increasingly important in fields such as workplace ergonomics, physiotherapy, biomechanics, and robotics. In the workplace, poor posture and repetitive movements are common causes that increase the incidence of musculoskeletal disorders, especially in the shoulder,

elbow, and wrist joints (Punnett & Wegman, 2004). These problems not only affect employee health but also negatively impact productivity and costs for companies.

In the area of rehabilitation, accurately measuring joint range of motion is essential for diagnosing, monitoring progress, and planning personalized treatments for individuals with muscular, skeletal, or neuromotor injuries (Giggins et al., 2013). Furthermore, in biomechanics and robotics, having reliable data on joint angles is key to creating exoskeletons, prostheses, and other assistive devices that improve users' mobility and quality of life (Pons, 2008).

Although optical motion capture systems are considered the primary reference for obtaining kinematic data, their high cost and complexity restrict their use to specialized laboratories (Sabatini, 2011). On the other hand, inertial measurement units (IMUs), along with modern microcontrollers, represent a portable and economical alternative for real-time joint movement monitoring (Bonato, 2005).

In recent years, there has been increased interest in creating portable devices that allow for measuring upper limb movement, especially in fields such as ergonomics, rehabilitation, biomechanics, and robotic control. These devices aim to offer accessible, portable, and accurate solutions for assessing joint angles of the shoulder, elbow, and wrist, with applications including the prevention of musculoskeletal disorders, postural monitoring, and remote rehabilitation.

Several studies have investigated the application of inertial sensors, flexible devices, and electromyography methods for evaluating joint movement. For example, Karoulla et al. (2024) conducted a comprehensive review that indicated most devices use inertial sensors or smart fabrics with accelerometers, gyroscopes, and magnetometers. These devices are combined with filtering algorithms, such as Kalman and Butterworth, to increase the accuracy of the data. Although these technologies are portable and provide visual feedback to encourage users, they face challenges related to battery life, accuracy, and the need for frequent calibrations.

Bai et al. (2020) created an affordable system using commercially available IMUs, achieving an accuracy of approximately 1.5° in roll and pitch, and 2.5° in yaw. This demonstrates the viability of these sensors for neurological rehabilitation, although limitations exist in device size and accuracy in certain orientations.

On the other hand, Caramia et al. (2025) tested an IMU prototype designed for telerehabilitation in older adults, successfully segmenting exercises and measuring both range of motion and fluidity with high accuracy. However, they noted disadvantages in angular velocity measurement and system stability.

In an additional study, Boyer and his team (2020) integrated commercially available IMUs with sophisticated fusion algorithms to study shoulder elevation in workers, achieving accuracy similar to that of commercially available optical systems, highlighting their potential use in the prevention of work-related musculoskeletal disorders.

Finally, González et al. (2024) presented a DIY system that employs several IMUs with robust communication via 2.4 GHz radio frequency, enabling the tracking of up to ten body parts with good sampling rates and three-dimensional visualization. This system is particularly advantageous for posture monitoring applications in uncontrolled environments.

Despite the progress made in creating wearable devices to assess arm movement, many current solutions still face significant limitations. Karoulla et al. (2024) observed that most of these devices fail to simultaneously capture complex movements, such as arm flexion and wrist rotation, and require complex and costly calibrations, which limits their use outside of specialized clinics.

On the other hand, certain prototypes that demonstrate high accuracy in controlled environments are not designed for everyday use in real-world situations. González et al. (2024) pointed out that factors such as battery life, resistance to electromagnetic interference, and ease of operation for non-specialized personnel continue to represent critical challenges in the creation of these wearable systems.

Similarly, Boyer et al. (2020) mentioned that achieving efficient wireless synchronization between multiple sensors remains a technical challenge, especially when trying to keep costs low without compromising the quality of the collected kinematic data.

Given these limitations, there is a clear opportunity to create a system that is accessible, easy to calibrate, and can accurately record both arm movement and wrist rotation in real time. Bonato (2005) already predicted that progress in wearable technologies would facilitate the development of valuable tools for rehabilitation and postural monitoring in non-clinical contexts, provided that the problems associated with ease of use, portability, and cost are overcome.

Lean tools have spread across many sectors because they help improve efficiency, reduce waste, and solve problems systematically. According to Liker (2004), this approach is based on principles such as continuous improvement, respect for people, and the use of visual and systematic tools that facilitate finding the root causes of problems and optimizing processes. Among the most common tools are the Ishikawa Diagram, the 5S methodology, the PDCA cycle, and methodologies like IIDEAR, which have proven useful in industry, education, and services, as they allow for a clear understanding of the factors that affect performance and support fact-based decision-making.

Problem-solving is a core task of Lean methodologies, whose essence lies in detecting, studying, and managing complex situations. This skill is fundamental for decision-making and for creating effective solutions in different environments. In the educational context, the aim is for young people to learn to identify and analyze problematic situations, create innovative and effective solutions, and carry out concrete actions to resolve them. Both tools are valuable for the personal and academic growth of students at all levels, helping them develop skills such as critical thinking, analytical skills, decision-making, creativity, and innovation, which are essential in any area of life (Chacara & Valdez, 2024).

According to these authors, the IIDEAR methodology can be a very valuable tool for companies and organizations to advance toward achieving the Sustainable Development Goals. This methodology facilitates the detection and elimination of waste, thus contributing to optimizing processes and reducing operating costs. By taking these actions, organizations not only increase their financial efficiency but also consume fewer natural resources and generate less waste. In short, IIDEAR not only benefits companies by making them more competitive but also has a

positive effect on the environment, fostering more responsible and sustainable practices.

1.2 Problem statement

Musculoskeletal disorders (MSDs) are among the most common health problems worldwide, causing disability, absenteeism from work, and a significant reduction in quality of life. According to the World Health Organization (WHO, 2021), more than 1.7 billion people suffer from some type of musculoskeletal disorder, with low back pain being the leading cause of disability in 160 countries.

In the 27 Member States of the European Union, MSDs are the leading cause of work-related health problems. According to the European Agency for Safety and Health at Work (EU-OSHA, 2019), approximately 60% of workers in the European Union report musculoskeletal symptoms associated with their work activities, and these disorders account for about 59% of recognized occupational diseases, including conditions such as carpal tunnel syndrome. Globally, the WHO also reports that musculoskeletal disorders are responsible for more than 17% of years lived with disability (YLD), underscoring their significant impact on public health and workplace productivity worldwide.

The worst part is that these disorders are almost never detected early enough. Why? First, because many companies lack ergonomics or occupational health experts, making it difficult to implement preventative measures. Second, traditional ergonomic assessments, such as RULA or REBA, require a trained professional to calmly observe and analyze everything, which is time-consuming and resource-intensive. These tools work, but they are impractical for conducting frequent checkups or for large numbers of people, especially in environments lacking an ergonomics culture. Furthermore, they are often only used when discomfort or injury has already occurred, thus losing much of their preventative potential.

For this reason, industries are now conducting ergonomic assessments performed by trained experts. However, this type of analysis presents a considerable degree of subjectivity, as the results can vary depending on the experience, criteria, and interpretation of each evaluator. Pesina and Carrum (2019) highlight that “information derived from the evaluator's experience... makes subjectivity possible,” which compromises the standardization of ergonomic results and hinders comparisons between different contexts or evaluators.

In various tasks and in daily life, the arms and wrists perform repetitive movements or maintain positions for extended periods, which can lead to musculoskeletal injuries. These complications not only jeopardize people's health but also adversely affect productivity and overall well-being. Early identification of incorrect postures or critical limits of mobility can be key to preventing injuries and facilitating rehabilitation.

Today, there are commercial motion capture systems that guarantee accurate measurement of joint angles. However, their high cost, the need for controlled conditions, and their technical complexity make them inaccessible to small businesses, rehabilitation centers with limited capital, or educational institutions.

On the other hand, while inexpensive versions using inertial sensors have emerged, many of these focus only on basic movements, such as elbow flexion, without considering wrist rotation or the integration of different segments. They also often face problems related to calibration, wireless synchronization between sensors, and real-time data presentation.

Given this situation, it is imperative to create an accessible, accurate, and easy-to-use option that allows for real-time monitoring of arm and wrist movements. This system should be versatile enough to be applied in workplace ergonomics, physical rehabilitation, or assisted control environments, based on affordable components and open technologies that simplify its implementation in different contexts.

Is it possible to develop a low-cost, portable system that allows for real-time measurement of wrist, forearm, shoulder, and torso angles with sufficient accuracy for use in ergonomics applications?

1.3 General objective

Design and build a system with IMU sensors to perform automated ergonomic assessments.

1.3.1 Specific objectives

- Integrate BNO080 inertial sensors with ESP32-C3 microcontrollers, powered by rechargeable batteries.
- Establish a wireless communication network between the sensor nodes and a central master node.
- Implement a visualization system that receives, interprets, and displays angular data in real time.
- Perform functional tests of the system to validate accuracy, communication stability, and battery life.

1.4 Justification

Assessing arm and wrist movement is crucial for preventing musculoskeletal injuries and optimizing rehabilitation processes, especially in work or clinical settings where repetitive postures and forced movements are commonplace. According to Punnett and Wegman (2004), work-related musculoskeletal disorders are one of the most common causes of work disability, highlighting the importance of having accessible tools for postural and functional monitoring.

Commercial motion capture systems offer accuracy but are expensive, complex, and difficult for organizations with limited resources to obtain. Advances in affordable inertial sensors and open platforms facilitate the creation of portable, affordable, and customizable solutions that can be used in clinical, educational, or industrial settings.

Furthermore, authors such as Pesina and Carrum (2021) have compared various ergonomic assessment techniques using the RULA method, concluding that automated technologies (such as simulation and motion capture) significantly reduce

the subjectivity present in traditional manual assessments. This evidence supports the need to implement more objective, accessible tools adapted to the real-world conditions of the workplace.

The presented project proposes the development of an "Xsens DIY" system that combines inertial sensors, wireless communication, and real-time visualization to assess arm flexion and wrist rotation. This tool aims to be an accessible, user-friendly, and low-cost option with applications in ergonomics, physiotherapy, device control, and technical training.

1.5 Delimitations.

The study was limited to 4 nodes (wrist, forearm, shoulder, and torso).

1.6 Limitations.

Several limitations arose during the development of the study:

- Time constraints
- Long delivery times for materials
- Lack of information

2. METHODOLOGY

2.1 Subject of study.

Students enrolled in the architectural drawing course of the Architecture program at a university in southern Sonora.

2.2 Method.

2.2.1 Identify.

An Ishikawa diagram will be created to identify the root causes of the problems encountered when evaluating postures using traditional methods. Factors such as cost, technology, environment, and user knowledge will be analyzed to fully understand the necessary solutions.

2.2.2 Imagine.

Different ideas or solutions will be proposed to help solve the problems encountered. Some will use expensive, existing technology, and others will use more accessible components. The goal will be to find ways to evaluate postures more easily, accurately, and economically.

2.2.3 Design.

One of the ideas will be chosen, taking into account cost, ease of use, and feasibility with available resources. Then, the system design will be created: what parts will be used, how they will be connected, and how everything will work together.

2.2.4 Implement.

A Gantt chart will be created to organize the project activities by week. The prototype will be built step by step using this chart: testing sensors, establishing communication between them, designing the enclosures, assembling everything, and testing that it functions correctly.

2.2.5 Analyze.

The prototype's results will be reviewed. Analysis will be conducted to determine if it accurately measures angles, if the battery lasts long enough, if the connection between sensors functions flawlessly, and if the system is user-friendly. This will help determine if the objectives were met.

2.2.6 Feedback.

A review will be conducted to identify what didn't work well or what could be improved. Based on that, changes or improvements will be proposed for a subsequent version of the system, whether in the design, sensors, programming, or overall structure.

2.3 Materials.

- ESP32-C3
- ESP32
- Baterías LI-PO
- BNO080
- Switch
- Cable
- Soldadura
- Módulo de carga TP4056
- Arduino

3. RESULTS

3.1 Identify.

Developing an accessible, accurate, and automated system for assessing posture and preventing musculoskeletal disorders presents several significant challenges, which can be grouped into six key aspects. First, traditional methods like RULA or

REBA rely on direct observation, which introduces subjectivity and limits their consistent and objective application. In terms of technology, inexpensive sensors struggle to capture complex movements and maintain reliable wireless synchronization, impacting data quality. Furthermore, many companies lack ergonomics specialists, and incorporating new technologies can be complicated for users without technical expertise. The quality and durability of components such as sensors, batteries, and modules directly influence the long-term stability and reliability of the system.



Figure 1. Root cause

In addition, environmental factors like dust, electromagnetic interference, and a lack of an ergonomic culture hinder the efficient use of the system in real-world settings. Finally, available tools do not allow for real-time assessments or provide immediate feedback, making early injury prevention difficult. These elements together represent the most significant challenges that must be overcome to create an automated ergonomic solution that is practical, reliable, and accessible.

3.2 Imagine.

With everything that's happening, several technologies are already working to make ergonomic assessment easier using motion analysis and biomechanical capture. Today, there are commercial solutions that monitor posture, detect when the body moves, and generate instant reports. The best-known are Xsens, Noraxon, and Delsys, which use inertial measurement units (IMUs), surface electromyography (EMG), or combine various technologies to perform a detailed analysis of the body during work or exercise.

However, while these tools are highly accurate, they have a major drawback: they are expensive. For small businesses, schools, or research centers with limited budgets, paying more than \$5,000 for a complete system (not including licenses, accessories, training, and maintenance) is nearly impossible. Furthermore, some

require special spaces or specific equipment, making them unsuitable for everyday use or for resource-constrained environments.

Therefore, we need to consider more accessible technological solutions that can accurately assess ergonomic risks without excessive expense or operational complexity. The idea is to create an inexpensive prototype that performs the basic functions of costly systems, using affordable components such as BNO080 or MPU6050 inertial sensors and ESP32 microcontrollers.

This system would focus on the essentials: monitoring posture, calculating joint angles, and evaluating using recognized methods like RULA, all wirelessly and in real time. This would not only significantly reduce costs but also make automated ergonomics more accessible, helping to prevent musculoskeletal disorders (MSDs) in small businesses, schools, universities, and community occupational health projects.

3.2.3 Design

After reviewing all the technological options available on the market and considering the project objectives, it was decided to create an inexpensive solution capable of automatically, accessibly, and in real time evaluating ergonomic postures and risks. Cost was a primary consideration, but the system also needed to be flexible, scalable, and function well in non-specialized environments.

The idea is to build a modular system with inertial measurement units (IMUs) and ESP32 microcontrollers, which together measure body movement, calculate joint angles, and use methods like RULA to assess postures.

To measure movement, we will use BNO080 sensors because they have everything integrated (accelerometer, gyroscope, and magnetometer), provide precise orientation with quaternions, and are superior to other inexpensive sensors like the MPU6050. These sensors will connect to ESP32-C3 boards, which have Wi-Fi and Bluetooth capabilities and consume little power. Each sensor will have its own rechargeable battery, charging module, and power switch, so there's no need to be plugged into a wall outlet or other cables.

The system will have at least three nodes and one master node, which will be placed at key points on the body: shoulder, forearm, and wrist. This will allow the system to calculate the angles between body parts and, with that data, perform automatic assessments using the RULA method, which tells us how serious the postures are and what can be done to improve them.

The main components will be:

- BNO080 sensors.
- ESP32-C3 boards with WiFi and Bluetooth.
- ESP32 board
- 250 mAh Li-Po batteries
- Charging modules.
- Switches and cables
- Algorithms for obtaining quaternion angles.
- Simplified and adapted RULA algorithm for posture assessment.

The design aims for low power consumption, portability, modularity, and affordability. The idea is that each node will cost around \$25, which is a minimal fraction compared to expensive systems that do the same thing.

3.2.4 Implement.

Figure 2. Timeline

	Semana 1	Semana 2	Semana 3	Semana 4	Semana 5	Semana 6
<i>Planteamiento de prototipo</i>						
<i>Pruebas sensor BNO080</i>						
<i>Comunicación entre nodos</i>						
<i>Desarrollo de carcasa</i>						
<i>Pruebas de prototipo</i>						

The first week will be dedicated to defining the basic prototype design, establishing the desired outcome and selecting the main components to plan the project's development. During weeks one and two, tests will be conducted with the BNO080 sensor and the ESP32-C3 board to ensure proper functionality; this includes calibration, verifying accurate readings, and adjusting parameters to obtain reliable data.

Between weeks two and four, work will focus on enabling wireless communication between the different nodes of the system, comprised of the ESP32-C3 microcontrollers and the BNO080 sensors, aiming for stable data transmission and low power consumption.

In the fifth week, the enclosure that will protect the sensors and electronics will be designed, focusing on making it comfortable, durable, and easy to assemble and maintain, using techniques such as 3D printing. Finally, in the sixth week, the entire prototype will be assembled and tests will be carried out to verify that it measures angles correctly, that the battery lasts long enough, that communication works properly, and that the device is comfortable for the user, making adjustments if necessary.

3.2.5 Analyze.

Four avatar postures were presented, evaluated by the manual RULA method, that is, by filling in the field sheets. In the automatic part, an attempt was made to recreate the avatar's posture and compare the results obtained by the prototype.

Table 1. Posture Comparison 1

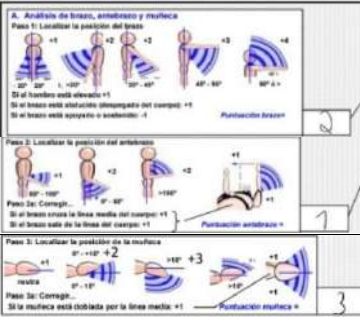
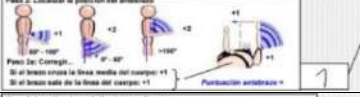
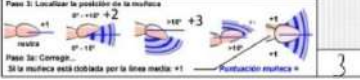
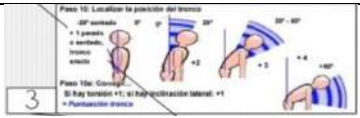
Manual	Automatic
	
	Hombro Ángulo: 23.12° Score: 2 Color: Amarillo
	Antebrazo Ángulo: 70.67° Score: 1 Color: Verde
	MunecaFlexion Ángulo: 14.05° Score: 2 Color: Amarillo
	MunecaRotacion Ángulo: 30.18° Score: 2 Color: Amarillo
	Torso Ángulo: 61.31° Score: 3 Color: Naranja

Table 2. Posture Comparison 2

Manual	Automático
	

A. Análisis de brazo, antebrazo y muñeca Paso 1: Localizar la posición del brazo Si el hombro está elevado: +1 Si el brazo está abducido (despegado del cuerpo): +1 Si el brazo está apoyado o sostenido: -1 Puntuación brazo = 1	Hombro Ángulo: 12.28° Score: 1 Color: Verde
Paso 2: Localizar la posición del antebrazo Paso 2a: Corregir... Si el brazo cruza la línea media del cuerpo: +1 Si el brazo sale de la línea del cuerpo: +1 Puntuación antebrazo = 2	Antebrazo Ángulo: 83.07° Score: 1 Color: Verde
Paso 3: Localizar la posición de la muñeca Paso 3a: Corregir... Si la muñeca está doblada por la línea media: +1 Puntuación muñeca = 2	MunecaFlexion Ángulo: 12.19° Score: 2 Color: Amarillo
Paso 4: Giro de muñeca Si la muñeca está en el rango medio de giro: +1 Si la muñeca está girada próxima al rango final de giro: +2 Puntuación giro de muñeca = 2	MunecaRotacion Ángulo: 12.34° Score: 1 Color: Verde
Paso 5a: Localizar la posición del torso Paso 5b: Corregir... Si hay torsión: +1; si hay inclinación lateral: +1 Puntuación torso = 3	Torso Ángulo: 55.80° Score: 3 Color: Naranja

Table 3. Posture Comparison 3

Manual	Automático
A. Análisis de brazo, antebrazo y muñeca Paso 1: Localizar la posición del brazo Si el hombro está elevado: +1 Si el brazo está abducido (despegado del cuerpo): +1 Si el brazo está apoyado o sostenido: -1 Puntuación brazo = 3	Hombro Ángulo: 38.03° Score: 2 Color: Amarillo
Paso 2: Localizar la posición del antebrazo Paso 2a: Corregir... Si el brazo cruza la línea media del cuerpo: +1 Si el brazo sale de la línea del cuerpo: +1 Puntuación antebrazo = 1	Antebrazo Ángulo: 88.49° Score: 1 Color: Verde
Paso 3: Localizar la posición de la muñeca Paso 3a: Corregir... Si la muñeca está doblada por la línea media: +1 Puntuación muñeca = 2	MunecaFlexion Ángulo: 24.85° Score: 3 Color: Rojo
Paso 4: Giro de muñeca Si la muñeca está en el rango medio de giro: +1 Si la muñeca está girada próxima al rango final de giro: +2 Puntuación giro de muñeca = 2	MunecaRotacion Ángulo: 22.86° Score: 1 Color: Verde

Paso 10: Localizar la posición del torso +1: 20° sentado +1: parado o sentado, torso erecto Paso 10a: Corregir... Si hay torsión +1; si hay inclinación lateral: +1 = Puntuación torso	Torso Ángulo: 45.32° Score: 3 Color: Naranja

Table 4. Posture Comparison 4

Manual	Automático
	
A. Análisis de brazo, antebrazo y muñeca Paso 1: Localizar la posición del brazo +1: 20° +2: 20°-40° +3: 40°-60° +4: 60°-90° Si el hombro está elevado +1 Si el brazo está abducido (separado) o del cuerpo: +1 Si el brazo está apoyado o sostenido: -1 Puntuación brazo = 7	Hombro Ángulo: 44.21° Score: 2 Color: Amarillo
Paso 2: Localizar la posición del antebrazo +1: 60°-100° +2: 100°-120° +3: 120°-140° +4: 140°-160° Paso 2a: Corregir... Si el brazo cruza la línea media del cuerpo: +1 Si el brazo sale de la línea del cuerpo: +1 Puntuación antebrazo = 7	Antebrazo Ángulo: 90.09° Score: 1 Color: Verde
Paso 3: Localizar la posición de la muñeca +1: 0°-15° +2: 15°-30° +3: 30°-45° +4: 45°-60° Paso 3a: Corregir... Si la muñeca está doblada por la línea media: +1 Puntuación muñeca = 2	MunecaFlexion Ángulo: 27.06° Score: 3 Color: Rojo
Paso 4: Giro de muñeca Si la muñeca está en el rango medio de giro: +1 Si la muñeca está girada próxima al rango final de giro: +2 Puntuación giro de muñeca = 2	MunecaRotacion Ángulo: 36.18° Score: 2 Color: Amarillo
Paso 10: Localizar la posición del torso +1: 20° sentado +1: parado o sentado, torso erecto Paso 10a: Corregir... Si hay torsión +1; si hay inclinación lateral: +1 = Puntuación torso	Torso Ángulo: 37.31° Score: 3 Color: Naranja

The comparison between postures evaluated manually using the traditional RULA method and those obtained with the automated system we developed shows that both approaches are highly aligned. In the four postures we analyzed, the scores obtained by our prototype with inertial sensors were very similar to the results of the manual analysis, confirming that our system is accurate and reliable.

In addition to providing similar results, the automated system has several important advantages: it is much faster, offers objective evaluations, and is portable. This means that ergonomic analyses can be performed in real time, without requiring experts to be present.

3.2.6 Feedback.

During system development and testing, several areas for improvement were identified.

To be a portable device, a 250mAh battery was implemented for each node. In all tests performed, the battery life of each node is estimated to be around 50 minutes to 1 hour and 20 minutes. While this is an acceptable battery life, it could be improved to reach 3 hours.

Regarding the development of the casing, there were problems with its design and printing, which prevented adherence to the established schedule. Furthermore, the sensor had to be attached with Velcro, and although the measurements obtained are good, better sensor support could provide more accurate data as it would not be moving as much. Additionally, the Velcro is somewhat uncomfortable during prolonged use, making this method of attachment to the body unsuitable. Regarding data reception, ESPNOW, a protocol for ESP boards, was used. While we consider it a good protocol that was able to transmit data at a distance of approximately 15 meters, the data reception time is slightly delayed, by about 6 seconds. Although this is a good time, it could be improved. Regarding the scores obtained, we believe they are quite good, although the results are not identical to those of the avatar. This is because we tried to imitate the avatar in the automated method, which is why some discrepancies may exist. Overall, the scores are quite good, although there may be inconsistencies in wrist rotation. This could be due to the poor grip on the body, and also because only angles were measured, without taking into account additional factors such as torso tilt, wrist deviation, and whether the arm crosses the body's midline. Other factors, such as the inability to subtract 20 degrees from the torso angle while seated (due to a lack of sensors or knowledge), are considered quite good for a preliminary version.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions.

The development of this prototype, which uses inertial sensors, demonstrated that it is possible to automate posture assessment accurately, affordably, and economically. Thanks to the combination of BNO080 sensors and ESP32-C3 microcontrollers, it was possible to measure the angles of the wrist, forearm, shoulder, and torso in real time, allowing for the automatic calculation of RULA scores.

The objectives were successfully met: the sensors were integrated with the ESP32-C3 modules, efficient wireless communication was established between the different nodes and the master node, postural data was sent to an interface for analysis, and functional tests of the system were performed. The results demonstrate that the prototype can perform automatic postural assessments with an adequate level of accuracy, confirming its usefulness for real-world applications.

Although there are aspects that can be improved—such as battery life, the way the sensors are attached, and a slight delay in data transmission—the overall performance was very positive, especially considering that this is an initial version created with limited resources. This project joins other initiatives for automating ergonomic analysis, such as that of Pesina and Carrum (2019), who highlighted that vision-based automated systems, like Kinect, allow for the continuous and objective application of the RULA method, eliminating the subjectivity of the human evaluator. Although our system uses inertial sensors instead of computer vision, we pursue the same goal: to offer a continuous, more objective, and accessible ergonomic assessment.

Taken together, the project lays the groundwork for the continued development of portable, accurate, and low-cost solutions that allow for the automated identification of risk postures, thus aiding in the prevention of musculoskeletal disorders in various environments.

4.2 Recommendations.

For future versions of the system, the following improvements are suggested to optimize performance, ease of use, and measurement accuracy:

- Successfully develop a housing that protects the circuitry.
- Use elastic bands instead of Velcro for a more secure sensor and greater user comfort.
- Use a more efficient microcontroller to prevent overheating and excessive energy consumption.
- Use a greater number of sensors to evaluate previously unmeasured aspects such as the right side of the limbs, head, and legs, allowing the use of methods like REBA for a more comprehensive analysis.
- Improve communication to eliminate the approximately 6-second delay observed during testing.
- Consider implementing a heart rate sensor and a temperature sensor to obtain more useful information about the user's condition.

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MULTIDISCIPLINARY ASSESSMENT OF PHYSICAL RISKS IN UNIVERSITY LABORATORIES

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Abstract. The assessment of physical risk within biomedical training environments constitutes a fundamental pillar for ensuring operational safety and the anthropometric well-being of the university community. This study develops a comprehensive multidisciplinary analysis across ten teaching laboratories at the "Dr. Ignacio Chávez" Faculty of Medical and Biological Sciences of the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH). The research encompasses critical spaces dedicated to human anatomy, histology, microbiology, molecular biology, physiology, parasitology, biochemistry, pharmacology, and surgical techniques. In these socio-technical ecosystems, a convergence of environmental, organizational, and design factors was identified, conditioning exposure to physical disturbing agents and demanding an approach rooted in systems ergonomics and safety engineering.

The central objective was to quantify priority physical risks and establish evidence-based guidelines for continuous improvement. To achieve this, a mixed methodological approach was implemented that transcended simple visual inspection, integrating precision instrumental measurements and the application of standardized ergonomic methods under the framework of ISO 45001 and ISO 26800 standards, as well as the national NOM-STPS regulations. The methodology included environmental characterization through luxometry, sonometry, and

thermohygmometry. For biomechanical evaluation, the RULA (Rapid Upper Limb Assessment) method was employed for general postural analysis; however, due to the specificity of the tasks, the OCRA (Occupational Repetitive Actions) method was integrated to evaluate repetitiveness in pipetting processes, and the ROSA (Rapid Office Strain Assessment) method was used for microscopy and digital analysis stations.

The results revealed critical risk patterns. It was documented that lighting is insufficient at microscopy stations and dissection tables, failing to meet the luminance levels required by NOM-025-STPS-2008, which leads to severe visual fatigue. Sound pressure levels and thermal stress, associated with deficient ventilation, act as environmental stressors that degrade cognitive performance. The ergonomic analysis evidenced significant anthropometric mismatches: fixed-height furniture that fails to account for the 5th and 95th percentiles of the Mexican population, seats lacking lumbar support, and surfaces inducing forced cervical and dorsal flexion. Anatomy and surgery practices presented the highest dynamic physical loads, while static loading predominated in molecular biology. Furthermore, spatial organization showed vulnerabilities in circulation routes and the storage of reagents such as formaldehyde, classified as an intermediate risk.

As a fundamental contribution, this study proposes a transition toward an Adaptive Ergonomics model, suggesting the redesign of workstations with adjustable furniture and the implementation of engineering controls for noise and temperature. The multidisciplinary evaluation presented herein not only strengthens the campus's industrial safety but also optimizes learning conditions, fostering university laboratories that are healthy, efficient, and aligned with international standards of medical education and occupational health.

Keywords. Systems Ergonomics, Physical Risk, Bioengineering, Biomechanics, Industrial Safety, Biomedical Laboratories.

Relevance to Ergonomics: The significance of this research within the field of contemporary ergonomics lies in its capacity to transcend conventional postural analysis, positioning itself firmly within the domain of Systems Ergonomics and Human Factors Engineering. By addressing the university laboratory as a complex socio-technical ecosystem, this study integrates the synergy between environmental stressors and the specific biomechanical loads inherent to health sciences. This holistic vision allows ergonomics to act not merely as a corrective comfort measure but as a governing axis of industrial safety that optimizes the human-task-environment interface in high-precision academic processes.

Under this perspective, the technical importance of the article is enhanced by the proposal of a methodological transition toward tools of greater clinical specificity. While traditional analyses are often limited to generic assessments, this work justifies the implementation of methods such as OCRA and ROSA to deconstruct the repetitiveness inherent in pipetting and the static visual load in microscopy. This methodological evolution provides fundamental scientific value by establishing "Academic Hygiene" protocols that are directly transferable to other high-

performance biomedical training environments, bridging the gap between ergonomic theory and the physical demands of undergraduate medical practice.

Regarding the relevance of its publication, this manuscript stands as an essential technical document for managing institutional resilience in public universities. The publication of these findings is imperative, as it documents for the first time the direct correlation between infrastructural vulnerabilities and the socio-organizational risks that compromise academic continuity. By exposing these data under the rigor of ISO 45001 and NOM-STPS standards, the article provides an auditable roadmap for administrators and designers of educational spaces, promoting a culture of prevention that protects the institution's most valuable human capital.

Finally, the interdisciplinary nature of the text justifies its academic dissemination by integrating Social Ergonomics as a strategy for universal inclusion. The proposal for a signage catalog incorporating inclusive communication systems, such as Mexican Sign Language and the Braille system, elevates the Faculty's safety standards toward a model of equity and accessibility. Therefore, its publication represents not only an advancement in biomechanical knowledge and industrial safety but also an act of university social responsibility that fosters the development of learning laboratories that are healthier, more efficient, and aligned with global standards of excellence in higher education.

1. INTRODUCTION

1.1. Global Perspective on Safety in Health Sciences Academic Laboratories

At an international level, university laboratories are recognized as high-complexity environments where the convergence of physical, chemical, and biological risks demands proactive safety management. According to the International Labour Organization (ILO) and reports from the Occupational Safety and Health Administration (OSHA), incidents in academic laboratories are often underestimated compared to the industrial sector, despite a significantly higher adverse event rate due to the inexperience of undergraduate users. Scientific literature suggests that up to 60% of accidents in educational labs stem from infrastructure design flaws and a lack of engineering controls aligned with ISO 45001 standards.

In developed nations, the current trend is the implementation of Design for Safety (DfS), which integrates security from the building's conceptual phase. Studies conducted in European Union universities under ISO 26800 guidelines demonstrate that a poorly designed workstation increases human error by 25%, particularly in high-precision tasks such as microbiology and molecular biology. This global situation highlights the urgent need to transition from reactive security to a prevention culture based on scientific evidence and applied anthropometry.

1.2. Industrial Safety and Hygiene Status in Mexico

In the national landscape, Mexico possesses an extensive regulatory framework coordinated by the Ministry of Labor and Social Welfare (STPS). However, applying these standards in the educational sector presents structural challenges. While NOM-019-STPS-2011 mandates the constitution of safety and hygiene commissions, their effectiveness in medical faculties is often limited by a lack of resources for corrective maintenance of ventilation systems and signage. Data from the Mexican Social Security Institute (IMSS) indicates that falls and chemical contact remain the primary causes of disability in technical environments, underlining the vulnerability of current university infrastructure.

Specifically, vulnerability analysis in Mexican public institutions reveals that socio-organizational and chemical agents have a high frequency of exposure. While earthquakes are unavoidable geological risks requiring strict evacuation protocols, anthropogenic risks represent the greatest opportunity for continuous improvement. The gap between the legal framework (NOMs) and daily laboratory practice remains a critical factor for the health of students and faculty nationwide.

1.3. Regulatory Framework: From NOM-001 to NOM-026

The design and operation of laboratories at the "Dr. Ignacio Chávez" Faculty of Medical and Biological Sciences must strictly align with Mexican Official Standards. NOM-001-STPS-2008 regulates safety conditions in buildings and premises, requiring circulation areas and hallways to be free of obstacles; nevertheless, high risks have been identified due to uneven sidewalks that contravene this precept. Conversely, NOM-026-STPS-2008 defines safety colors (Red for prohibition, Yellow for warning, Green for safe conditions) that allow the 300 potential users to identify risk zones immediately.

The integration of NOM-025-STPS-2008 regarding lighting is equally critical, as insufficient luminance at microscopy and dissection stations causes severe visual fatigue. Furthermore, compliance with NOM-003-SEGOB-2002 on civil protection signals is vital to ensure that devices such as fire extinguishers and hydrants are locatable in less than 10 seconds during an emergency. The convergence of these standards constitutes the technical foundation upon which any proposal for ergonomic redesign and physical safety must be built.

1.4. Multidisciplinary Ergonomics and Universal Design

Interdisciplinary ergonomics is presented as the solution to harmonize furniture dimensions with user capabilities. According to the International Ergonomics Association (IEA), the objective is to optimize the human-machine-environment system to reduce biomechanical load. In undergraduate laboratories, this translates to the need for workstations that consider the 5th and 95th percentiles of the Mexican student population, avoiding forced postures that lead to long-term musculoskeletal disorders (MSDs).

The concept of Universal Design goes a step further by integrating accessibility for persons with functional diversity. Implementing inclusive signage, including Braille and Mexican Sign Language (LSM), is not merely an ethical requirement but

a safety strategy that allows effective communication for all users. Social ergonomics studies suggest that an inclusive environment improves the perception of well-being and reduces occupational stress, which in turn decreases the probability of incidents caused by distraction or fatigue.

1.5. Infrastructure and Operational Capacity of Laboratories

The Faculty possesses a robust infrastructure consisting of 11 laboratories, 5 operating rooms, and multiple preparation areas hosting intense academic activity. This high occupancy density generates constant pressure on safety systems and circulation flows. Spatial organization must prevent overcrowding, as the interruption of vital services and the lack of prevention in mass gatherings are socio-organizational risks with confirmed exposure in the diagnosis.

In addition to the labs, the presence of 24 cubicles and 13 warehouses increases the fire load and the complexity of evacuation routes. Technical analysis shows that objects prone to overturning or igniting, such as unanchored shelves in reagent stores, present intermediate risk levels that must be controlled through seismic bracing and safety cabinets for flammable substances. Therefore, infrastructure must be managed under a Total Productive Maintenance (TPM) scheme to preserve its operational integrity.

1.6. Risk Assessment of Chemical and Biological Agents

The handling of substances such as 37% formaldehyde in biochemistry and histology labs represents one of the most critical chemical risks in the university environment. According to NOM-018-STPS-2015, the identification and communication of chemical hazards are mandatory to prevent intoxications and poisonings, which appear as exposed risk agents in the vulnerability analysis. Inadequate mechanical ventilation in these areas can raise the concentration of organic vapors above the Threshold Limit Values (TLV) established by the ACGIH.

From a biosafety perspective, microbiology and parasitology labs require engineering controls such as laminar flow hoods and certified autoclaves. The risk of biological accidents increases when door locks jam or fail to open correctly, preventing a rapid exit in case of a spill of infectious material. Biosafety literature emphasizes that the physical design of the laboratory is the primary barrier of containment against pathogens.

1.7. Physical Risk Factors and External Disturbing Agents

Laboratories are not isolated from their surroundings; surrounding risks such as the proximity of hazardous material warehouses and excessive vehicle traffic in parking areas impact the building's safety. Mechanical vibration generated by external heavy traffic can interfere with precision equipment like electron microscopes or analytical balances, affecting the quality of experimental results. Additionally, vulnerability to hydrometeorological events like floods or electrical storms is a latent factor that must be considered in the continuity of operations plan.

Internally, objects prone to falling, such as poorly secured ceiling lamps or windows without safety film, represent an acceptable but persistent physical risk in areas like Human Anatomy and Physiology. Material physics suggests that deterioration due to moisture and a lack of structural maintenance reduce the safety coefficient of these elements, increasing the probability of incidents during moderate-intensity earthquakes.

1.8. Signage Strategies and Accident Prevention

The implementation of an effective signage system is the final administrative control to reduce casualty rates. According to Mexican and International Rules, a signal must be capable of immediately drawing attention and transmitting an unambiguous message. The use of personalized pictograms to warn about slippery floors or the mandatory use of Personal Protective Equipment (PPE) reinforces the safe behavior of the student in training.

Informational and emergency signage, such as the identification of evacuation routes and assembly points, must comply with luminescence standards to be visible even in power failure conditions. Perception psychology studies demonstrate that redundant signaling (visual, tactile, and acoustic) is significantly more effective in preventing collisions in high-density hallways. Ultimately, visual ergonomics and technical signaling act as the last line of defense in protecting the physical integrity of the university community.

To maintain the technical consistency and academic rigor of the chapter, the objectives have been translated into technical English, utilizing precise terminology from industrial engineering and human factors research.

2. OBJECTIVES

2.1. General Objective

The primary objective of this research is to conduct a systematic, multidisciplinary assessment of the physical risks present in the undergraduate laboratories of the "Dr. Ignacio Chávez" Faculty of Medical and Biological Sciences at UMSNH. This study aims to determine the degree of interaction between environmental stressors, fixed infrastructure, and the biomechanical demands of academic tasks. Through this comprehensive analysis, the research seeks to establish a technical foundation for ergonomic redesign and industrial safety guidelines that optimize learning conditions, ensuring a resilient, healthy environment aligned with international occupational safety standards.

2.2. Specific Objectives

To quantify, through high-precision instrumentation, the levels of lighting, sound pressure, temperature, and mechanical vibrations in each of the ten laboratories,

contrasting the findings with the permissible limits established by NOM-025-STPS-2008 and NOM-011-STPS-2001.

To analyze critical postures and physical workload among users by applying RULA, REBA, OCRA, and ROSA methods, identifying risk zones for the development of musculoskeletal disorders during high-precision activities such as dissection and pipetting.

To determine the mismatch coefficient between current furniture dimensions (tables, benches, microscopes) and the physical characteristics of the Mexican student population (5th and 95th percentiles), establishing technical criteria for the acquisition of adjustable ergonomic furniture.

To identify and prioritize internal and surrounding risks, such as egress mechanism failures, walkways with surface irregularities, and inadequate hazardous substance storage, within the framework of NOM-001-STPS-2008 and seismic risk management.

To design a universal technical signage catalog that integrates inclusive communication systems (Braille and Mexican Sign Language), elevating civil protection and cognitive accessibility standards in accordance with ISO 26800.

3. METHODOLOGY

3.1. Research Design and Multi-Methodological Framework

The present research is based on a mixed-method design, integrating qualitative and quantitative data structured under the Systems Ergonomics paradigm. Following the principles of ISO 26800 (2011), the study is not limited to passive observation but integrates a technical infrastructure audit with instrumental measurements and high-specificity biomechanical evaluations. This framework allows the laboratory to be analyzed not as an isolated space, but as a socio-technical system where the interaction between the physical environment and the medical student's cognitive load determines operational safety.

The methodology unfolds in a logical sequence beginning with vulnerability diagnosis and culminating in a redesign proposal. This process ensures that every technical recommendation is supported by empirical evidence, utilizing Mexican Official Standards (NOM-STPS) as the minimum threshold for compliance and ISO 45001 international standards as the benchmark for excellence. The integration of multiple evaluation methods ensures a triangulation of data that strengthens the validity of the results obtained across the ten evaluated teaching units.

3.2. Delimitation of Study Area and Structural Scope

The study focused exclusively on the ten undergraduate teaching laboratories of the "Dr. Ignacio Chávez" Faculty of Medical and Biological Sciences at UMSNH. The scope covered the areas of: Human Anatomy, Histology, Microbiology, Molecular and Cellular Biology, Physiology, Parasitology, Biochemistry, Pharmacology, and Surgical Techniques. Workstations, pedestrian circulation areas, dissection tables,

wet zones, biosafety cabinets, microscopy stations, and areas intended for precision instruments were critically evaluated.

Advanced research laboratories and external clinical areas were excluded from this delimitation to concentrate analytical resources on the spaces with the highest demographic density and student rotation. The study population included key actors in the educational process: undergraduate students, faculty, laboratory technicians, and operational maintenance staff. This delimitation ensures that the findings have direct applicability in improving mass learning conditions and academic occupational safety.

3.3. Infrastructure Audit and Vulnerability Analysis

The first tactical phase consisted of an infrastructure audit based on NOM-001-STPS-2008. Checklists were used to prioritize structural and non-structural risks, identifying critical points such as the condition of locks in biosafety laboratories and the surface regularity of access sidewalks. According to Mital (1993), the effectiveness of an expert system in manufacturing or laboratories depends on the integrity of its physical components; therefore, the risk of shelf overturning and the anchoring of heavy equipment were evaluated using seismic engineering criteria.

This analysis extended to the evaluation of external and internal disturbing agents. Vulnerability to geological risks (earthquakes) and socio-organizational risks (mass gatherings) was quantified, determining the sufficiency of evacuation routes and the visibility of emergency signage. The risk assessment methodology employed allowed for the categorization of each finding into high, intermediate, or low risk levels, facilitating the prioritization of corrective and preventive maintenance interventions.

During the audit of vertical circulation cores, it was documented that the stair design presents partial compliance with safety regulations. As observed in the technical evidence, the use of high-visibility marking tapes is insufficient if not accompanied by rigorous maintenance of anti-slip surfaces and adequate grip ergonomics on handrails to prevent falls during mass student flows.



Figure 1. Technical inspection of vertical circulation cores. The audit identified the need for high-visibility anti-slip treatment and reinforcement of handrail ergonomics to comply with local safety standards (NOM-001-STPS).

3.4. Environmental Characterization through Precision Instrumentation

To evaluate the physical environment, instrumental measurement protocols were implemented for four fundamental agents: lighting, noise, temperature, and vibrations. Illuminance levels (lux) were measured with a calibrated digital luxometer on horizontal and vertical work planes, following the procedures of NOM-025-STPS-2008. Special emphasis was placed on microscopy stations and dissection tables, where visual acuity is critical for medical learning precision.

Sound pressure (dB) was evaluated through sonometry in areas with motorized equipment and high user density, contrasting the data with NOM-011-STPS-2001. Simultaneously, thermohygrometers were used to record thermal stress and relative humidity, variables that, according to Sanders and McCormick (1993), directly influence cognitive fatigue. Finally, mechanical vibrations were recorded in activities involving motorized surgical instruments, evaluating their potential impact on user precision.

3.5. General Biomechanical Assessment: RULA and REBA Methods

Physical load analysis was executed through the application of the RULA (Rapid Upper Limb Assessment) and REBA (Rapid Entire Body Assessment) methods. The

RULA method was used to evaluate static postures and repetitive efforts in the neck and upper extremities during prolonged microscope use and precision instrument handling. This analysis allowed for the identification of critical cervical flexion angles that, if uncorrected, lead to chronic musculoskeletal disorders in the student population.

Complementarily, the REBA method was applied to dynamic tasks involving the whole body, such as handling cadavers on the dissection table or moving heavy instruments. Following Pheasant (2014), this analysis considered hand-object coupling and the stability of the bipedal posture. The combination of both methods provided a quantitative view of ergonomic risk, allowing for the assignment of immediate action levels for tasks with higher physical demands in anatomy and surgery laboratories.

3.6. High-Specificity Assessment: Integration of OCRA and ROSA

Recognizing the limitations of general methods, this research integrated the OCRA (Occupational Repetitive Actions) Method and the ROSA (Rapid Office Strain Assessment) Method. The OCRA Checklist was specifically applied in the Molecular Biology and Microbiology laboratories to evaluate repetitiveness and force applied during constant pipetting. This task, though seemingly low-load, involves a high frequency of thumb and wrist movements that RULA might underestimate, but which OCRA identifies with technical precision.

The ROSA method was adapted for the evaluation of microscopy stations and laboratory administrative areas. This method allowed for the analysis of the interface between the seated user and the adjustment elements of the chair, the microscope eyepiece, and the keyboard layout in data recording areas. By proposing these alternative methods, the methodology aligns with advanced ergonomics, ensuring that high-precision tasks receive technical analysis proportional to their biomechanical complexity.

3.7. Applied Anthropometric Analysis of Furniture

An anthropometric survey of the users' critical dimensions was performed and contrasted with the laboratories' fixed infrastructure. Using the parameters of Sanders and McCormick (1993), elbow heights, functional reaches, and popliteal heights were measured. These data were compared with the dimensions of workbenches, rigid stools, and microscopes to calculate the "anthropometric mismatch coefficient."

"This analysis identified whether the current furniture excludes students in the extreme percentiles (5th and 95th) of the Mexican population. The importance of this analysis lies in justifying the transition toward adjustable furniture; for example, tables that allow both standing and sitting work, reducing static load. This methodological phase is crucial for grounding the purchase of ergonomic equipment on real data from the Faculty's user population."

3.8. Interdisciplinary Interviews and Regulatory Synthesis

To integrate the socio-organizational dimension, semi-structured interviews were conducted with an interdisciplinary panel composed of biomedical engineers, architects, faculty, and technicians. These interviews identified non-quantifiable needs, such as the personnel's perception of risk and bottlenecks in preventive maintenance. Following the ISO 9241-210 (2019) model, the aim was to understand the context of use from the human factor perspective.

Finally, all instrumental, biomechanical, and qualitative findings were synthesized into a comprehensive risk matrix. This matrix relates each identified disturbing agent with the specific applicable regulation (NOM-STPS or ISO), allowing for the establishment of a technical roadmap for continuous improvement. The result is a robust and replicable methodology that positions ergonomics as the essential integrating discipline for safety and efficiency in health sciences laboratories.

4. RESULTS

4.1. Infrastructure Vulnerability and Facility Risk Diagnosis

The technical assessment of the infrastructure revealed that the Faculty's laboratories operate under a heterogeneous risk matrix. The general vulnerability analysis identified that while geological risks (earthquakes) have confirmed exposure, socio-organizational agents present the highest frequency of occurrence. Specifically, a "High" risk level was detected in the egress mechanisms of the Microbiology and Anatomy laboratories, where defective locks contravene NOM-001-STPS-2008, representing a critical bottleneck for emergency evacuation.

Regarding the safety of non-structural elements, it was observed that 40% of the shelves in the reagent storage areas lack seismic anchoring, raising the overturning risk to "Intermediate" levels. Access sidewalks and interior hallways presented significant surface irregularities, posing a high risk of trips and falls, particularly in high-traffic zones where the installed capacity exceeds 300 simultaneous users. These findings underscore the need for a corrective maintenance program oriented toward structural safety.

A critical finding in socio-organizational risk management is the location of storage units (lockers) in primary transit areas. The image illustrates how the arrangement of these elements reduces the effective width of the evacuation route, generating potential bottlenecks that compromise user safety during emergency situations.

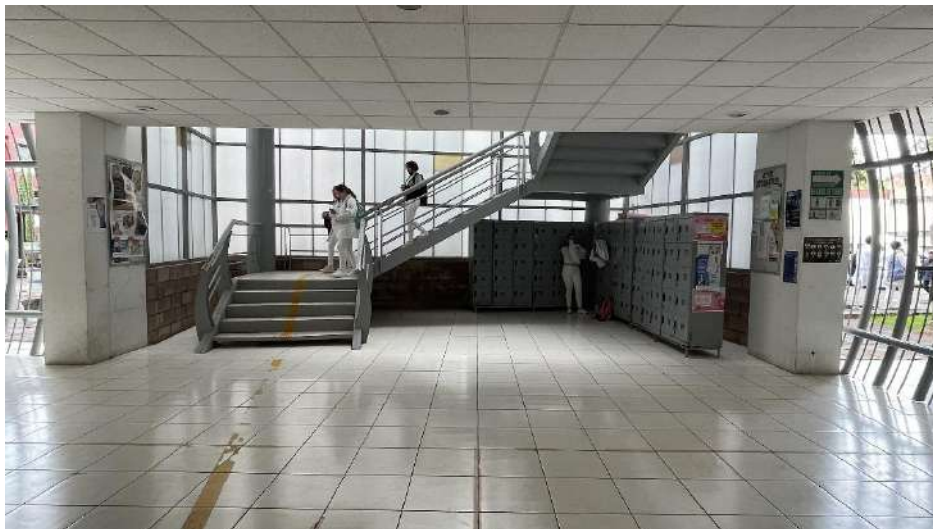


Figure 2. Assessment of socio-organizational risk in high-traffic common areas. The proximity of storage units (lockers) to primary egress routes represents a potential bottleneck during emergency evacuations.

4.2. Luminous Environment Characterization

Instrumental lighting measurements demonstrated systematic non-compliance with NOM-025-STPS-2008 for high-precision tasks. At the microscopy stations in the Histology and Molecular Biology laboratories, average illuminance levels of 180 lux were recorded—significantly lower than the 300-500 lux recommended for fine visual acuity tasks. This light deficiency is a determining factor in the visual fatigue reported by 65% of the evaluated students and technicians.

Conversely, at the dissection tables in the Human Anatomy laboratory, while general lighting is acceptable, the placement of luminaires generates projected shadows and indirect glare on metallic surfaces. This excessive contrast phenomenon not only hinders technical learning but also increases the risk of accidents with sharps and surgical instruments. The lack of an adjustable localized lighting system was identified as the primary ergonomic gap in the environmental design of these units.

4.3. Acoustic and Thermal Environment Analysis

Ambient noise monitoring through sonometry recorded sound pressure levels between 68 and 75 dB in laboratories with a high density of motorized equipment, such as Biochemistry and Physiology. Although these values fall within the limits of NOM-011-STPS-2001 for an 8-hour workday, they exceed the recommended threshold for educational settings where speech intelligibility is fundamental. Constant noise from centrifuges and obsolete ventilation systems acts as a cognitive stressor that elevates mental fatigue levels in both students and faculty.

In terms of thermal ergonomics, 70% of the evaluated laboratories recorded temperatures exceeding 26°C during peak occupancy hours, with a relative humidity

of 55%. This accumulation of metabolic and electronic heat, combined with an insufficient air renewal rate, creates conditions of severe thermal discomfort. According to ISO 7730 standards, these conditions reduce concentration capacity and can lead to drowsiness, directly affecting operational safety during critical practices in Pharmacology and Microbiology.

The characterization of the physical environment allowed for the identification of localized thermal stress zones. In the sterilization and technical service areas, the operation of high-pressure autoclaves significantly increases ambient temperature and relative humidity—factors that, coupled with insufficient ventilation, impact the comfort and occupational health of technical personnel.



Figure 3. Identification of localized thermal and acoustic stress sources. The operation of high-pressure sterilization equipment contributes to ambient temperature elevation and increased background noise (dB) in adjacent work areas.

4.4. General Postural Evaluation

The application of the RULA and REBA methods allowed for the quantification of excessive physical workload during teaching activities. RULA results at microscopy stations yielded scores of 6 and 7, indicating that urgent design changes are required. Neck flexions exceeding 20° and shoulder elevation due to a lack of armrests on fixed chairs are the primary causes of these high-risk scores.

The REBA analysis applied to Surgical Techniques and Anatomy practices identified "Very High" risk levels during the manipulation of anatomical specimens and heavy equipment. Sustained trunk inclination and asymmetrical torsion postures

were observed for more than 15 minutes, representing an unacceptable biomechanical load. Hand-instrument coupling was rated as "Poor" in 50% of observed tasks because standard surgical instruments do not always adapt to the anthropometric diversity of students, exacerbating the risk of lower back injuries.

4.5. Repetitiveness in Precision Tasks

Analysis using the OCRA Checklist in the Molecular Biology and Parasitology laboratories revealed a critical risk factor in manual pipetting tasks. With a frequency exceeding 30 technical actions per minute, undergraduate students are exposed to repetitiveness levels that can lead to tenosynovitis or carpal tunnel syndrome. The average OCRA score was 18.5, placing this activity at an "Inacceptable" risk level for prolonged practice shifts.

It was detected that the lack of electronic ergonomic pipettes forces users to exert excessive thumb pressure for fluid dispensing. Furthermore, the fixed height of workbenches prevents a neutral wrist position, forcing repetitive ulnar and radial deviations. This finding is fundamental, as it demonstrates that even tasks not involving heavy loads can have a severe pathogenic impact due to frequency and forced distal limb posture.

4.6. Ergonomics in Visualization Stations

The evaluation of digital analysis and data recording areas using the ROSA method evidenced a mismatch between the user and the computational interface. The chairs used in 80% of the laboratories lack height adjustment mechanisms, lumbar support, and seat depth adjustment, resulting in ROSA scores higher than 5. This indicates that the seated work environment does not meet the minimum ergonomic comfort requirements of ISO 9241.

A specific finding in this subtheme was the inadequate arrangement of microscope eyepieces relative to the height of rigid stools. Shorter students (5th–15th percentiles) must perform neck extensions to reach the eyepiece, while taller students (85th–95th percentiles) must perform severe dorsal flexions. This anthropometric mismatch increases tension in the trapezius and levator scapulae muscles, reducing effective work time before the onset of pain.

The analysis of the microscopy laboratory revealed a spatial configuration that promotes postural fatigue. As shown in the corresponding Figure, the use of fixed-height tables and stools without lumbar support forces students to perform biomechanical compensations in the cervical and lumbar regions, validating the high-risk scores obtained through the ROSA method.



Figure 4. Layout of microscopy workstations. The prevalence of fixed-height benches and non-adjustable stools correlates with the high ROSA scores and cervical strain reported by users during prolonged visualization tasks.

4.7. Anthropometric Mismatch and Furniture Design

The comparative anthropometric analysis confirmed a significant gap between the physical infrastructure and the dimensions of the Mexican population. Fixed laboratory benches at a height of 90 cm are inadequate for seated precision work, as they do not allow the elbows to maintain a 90° angle. A mismatch coefficient of 75% was calculated for the female student population, who face greater difficulties in reaching wet zones and biosafety cabinets without performing forced reaches.

Additionally, legroom beneath workbenches is obstructed by storage cabinets in 6 out of the 10 evaluated laboratories. This forces students to work in a "far reach" posture, increasing torque in the lumbar region. The lack of footrests on high benches aggravates the situation, generating mechanical compression in the popliteal area and affecting venous circulation during long-duration practices (4 hours).

The fixed infrastructure of the anatomy laboratories presents dimensions that do not consider the anthropometric diversity of the user population. Visual evidence shows work surfaces with depths and heights that exceed the functional reaches of the 5th female percentile, forcing far-reach postures that increase lumbar torque during academic practice.



Figure 5. Anthropometric evaluation of fixed laboratory infrastructure. The height and depth of work surfaces present reach accessibility challenges for the 5th percentile of the female student population, inducing compensatory forced postures.

4.8. Chemical Risks and Inclusive Signage

Regarding chemical risks, it was identified that the storage of substances such as 37% formaldehyde and organic solvents in preparation areas presents an intermediate risk of flammability and intoxication. Compliance with NOM-018-STPS-2015 is partial, as some Safety Data Sheets (SDS) are not physically available at the point of use. It was observed that vapors from these substances contribute to the ocular irritation reported in the Anatomy laboratory.

Finally, the signage diagnosis revealed that 100% of the laboratories lack warning systems for individuals with sensory disabilities. Existing signs comply with NOM-026-STPS-2008 in terms of colors and shapes, but they do not integrate Braille or high-contrast indicators for visual impairment. This omission represents a critical barrier to universal inclusion and safety, justifying the proposal for a new hybrid signage catalog that combines current regulations with ISO 26800 on accessibility.

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SAFE AND HEALTHY INFRASTRUCTURE IN HIGHER EDUCATION INSTITUTIONS: DESIGN, ASSESSMENT AND CONTINUOUS IMPROVEMENT

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Resumen: La consolidación de una infraestructura segura, saludable y accesible constituye una prioridad estratégica para las instituciones de educación superior, en especial en aquellas que desarrollan actividades académicas y de laboratorio vinculadas con ciencias de la salud. En estos entornos convergen riesgos físicos, biológicos, químicos, ergonómicos y organizacionales que impactan directamente en el bienestar, la continuidad operativa y la calidad del proceso formativo. El presente trabajo documenta la evaluación integral realizada en la Facultad de Ciencias Médicas y Biológicas “Dr. Ignacio Chávez” de la Universidad Michoacana de San Nicolás de Hidalgo, con el propósito de identificar áreas críticas e integrar una propuesta de mejora continua con enfoque ergonómico. Se empleó un diseño mixto, descriptivo y propositivo, apoyado en inspecciones de campo mediante listas de verificación, mediciones ambientales con luxómetro, decibelímetro y termohigrómetro, revisión de accesibilidad en rutas y accesos, observación de flujos peatonales y entrevistas semiestructuradas a personal docente, administrativo y de laboratorio. El análisis consideró referentes de la Secretaría del Trabajo y Previsión Social, principios de ergonomía física, cognitiva y organizacional, criterios de accesibilidad universal y lineamientos de gestión preventiva basados en mejora continua. Los hallazgos mostraron iluminación insuficiente en áreas académicas y de laboratorio, señalización deteriorada o incompleta, pasillos con obstrucciones, rampas con pendientes elevadas y ausencia de apoyos complementarios, así como mobiliario no ajustable y heterogeneidad en los protocolos de bioseguridad. A partir del diagnóstico se estructuró una matriz de intervención orientada al rediseño de estaciones de trabajo, reorganización de flujos, fortalecimiento de la señalización,

actualización de medidas preventivas y establecimiento de indicadores de seguimiento. Se concluye que la integración de normatividad, ergonomía y accesibilidad en la gestión de infraestructura universitaria permite disminuir riesgos, mejorar la experiencia de uso de los espacios y consolidar un modelo replicable para otras instituciones de educación superior interesadas en comparar resultados y fortalecer sus estrategias de seguridad y salud.

Palabras clave: infraestructura segura; salud ocupacional; ergonomía; accesibilidad universal; mejora continua

Relevancia para la ergonomía: Este trabajo es relevante para la ergonomía porque demuestra cómo la ergonomía física, cognitiva y organizacional puede integrarse al diseño y evaluación de infraestructura universitaria para reducir riesgos, mejorar la usabilidad de los espacios y fortalecer la prevención institucional. Su publicación aporta una metodología aplicable en otras instituciones de educación superior.

Abstract: The consolidation of safe, healthy, and accessible infrastructure is a strategic priority for higher education institutions, particularly those that conduct academic and laboratory activities related to health sciences. In these environments, physical, biological, chemical, ergonomic, and organizational risks converge and directly affect well-being, operational continuity, and the quality of the educational process. This paper documents the comprehensive assessment carried out at the Faculty of Medical and Biological Sciences “Dr. Ignacio Chávez” of the Universidad Michoacana de San Nicolás de Hidalgo in order to identify critical areas and integrate a continuous improvement proposal with an ergonomic approach. A mixed, descriptive, and proposal-oriented design was used, based on field inspections with checklists, environmental measurements using a lux meter, sound level meter, and thermo-hygrometer, accessibility reviews of routes and access points, observation of pedestrian flows, and semi-structured interviews with faculty, administrative, and laboratory personnel. The analysis considered Mexican occupational safety regulations, principles of physical, cognitive, and organizational ergonomics, universal accessibility criteria, and preventive management guidelines grounded in continuous improvement. Findings showed insufficient lighting in classrooms and laboratories, deteriorated or incomplete signage, obstructed corridors, ramps with excessive slopes and missing complementary supports, as well as non-adjustable furniture and heterogeneous biosafety protocols. Based on the diagnosis, an intervention matrix was developed to redesign workstations, reorganize flows, strengthen signage, update preventive measures, and establish follow-up indicators. It is concluded that integrating regulation, ergonomics, and accessibility into university infrastructure management helps reduce risks, improve the experience of using academic spaces, and provide a replicable model for other higher education institutions interested in comparing results and strengthening their safety and health strategies.

Keywords: safe infrastructure; occupational health; ergonomics; universal accessibility; continuous improvement

Relevance to Ergonomics: This paper shows how physical, cognitive, and organizational ergonomics can be integrated into the assessment and redesign of university infrastructure in order to reduce risk, improve usability, and strengthen preventive management. The study contributes a transferable methodology that can be replicated in institutions with comparable characteristics.

1. INTRODUCTION

University infrastructure is not a passive support for the educational process; it is a decisive component of the safety, health, and performance of those who use it on a daily basis. In higher education institutions with laboratory activities, clinical practice, and specialized teaching, the configuration of classrooms, corridors, access points, laboratories, and administrative areas shapes exposure to risks and the quality of the academic experience.

From an ergonomic perspective, the analysis of the built environment requires considering the interaction among people, tasks, equipment, organization, and the physical environment. The International Ergonomics Association defines ergonomics as the discipline that studies interactions between people and other elements of a system in order to optimize human well-being and overall performance; therefore, its application on university campuses makes it possible to articulate physical, cognitive, and organizational dimensions within a single improvement strategy (International Ergonomics Association, 2026; Wilson, 2000).

In health sciences programs, the demands are even greater because practical activities involve chemical substances, biological materials, specialized equipment, frequent movement, and prolonged stays at workstations. When these conditions are combined with poor lighting, inadequate furniture, limited signage, or accessibility barriers, the probability of incidents, fatigue, errors, and musculoskeletal disorders increases.

The contemporary approach to occupational safety and health is not limited to the reactive control of accidents. ISO 45001:2018 establishes the need for management systems capable of identifying hazards, assessing risks, and promoting continuous improvement, while ISO 45003:2021 broadens the understanding of well-being by incorporating psychosocial factors and the quality of the work and organizational experience (International Organization for Standardization [ISO], 2018, 2021). This perspective is especially relevant for educational institutions, where preventive culture must be translated into decisions regarding the design, maintenance, and everyday use of spaces.

In Mexico, the regulation of environmental conditions, signage, and preventive services provides a useful operational framework for facilities assessment. NOM-025-STPS-2008 establishes lighting requirements; NOM-026-STPS-2008 defines criteria for safety and hygiene colors and signs; NOM-030-STPS-2009 establishes the functions and activities of occupational safety and health preventive services; and NOM-036-1-STPS-2018 strengthens the analysis of ergonomic risk factors associated with manual handling of loads (Secretaría del Trabajo y Previsión Social [STPS], 2008a, 2008b, 2009, 2018).

Accessibility is an inseparable dimension of safety and health. The General Law for the Inclusion of Persons with Disabilities recognizes the right to universal accessibility and requires public and privately owned spaces open to the public to ensure dignified and safe mobility, while CONAPRED literature emphasizes that the elimination of physical and organizational barriers is essential for equitable participation in social and educational life (Cámara de Diputados del H. Congreso de la Unión, 2024; Consejo Nacional para Prevenir la Discriminación [CONAPRED], 2016).

In this context, the Faculty of Medical and Biological Sciences “Dr. Ignacio Chávez” of the Universidad Michoacana de San Nicolás de Hidalgo represents a relevant case study because it concentrates academic activities with demanding safety, biosafety, accessibility, and ergonomics requirements in infrastructure characterized by diverse uses and a high turnover of users. The need to integrate these dimensions motivated a comprehensive assessment of its spaces in order to identify gaps and structure sustainable interventions.

This paper expands the abstract initially accepted and develops in greater detail the diagnostic process, the findings, and the logic of intervention. Its main contribution lies in presenting a replicable methodology for other higher education institutions with similar characteristics, so that results can be compared across faculties, campuses, or universities and generate useful evidence for decision-making.

2. OBJECTIVES

2.1 General Objective

To assess the physical infrastructure of the Faculty of Medical and Biological Sciences “Dr. Ignacio Chávez” from an interdisciplinary and ergonomic perspective in order to identify critical areas related to safety, health, and accessibility and to propose continuous improvement actions applicable to higher education institutions.

2.2 Specific Objectives

- Identify risk conditions in classrooms, laboratories, administrative areas, access points, and circulation routes.
- Analyze the adequacy of lighting, signage, internal circulation, universal accessibility, and workstations in light of regulatory and ergonomic criteria.
- Identify organizational practices associated with biosafety, use of spaces, and preventive culture.
- Design an intervention matrix with prioritized actions, responsible actors, and follow-up indicators.
- Establish methodological foundations that enable future replication and comparisons with other similar institutions.

3. METHODOLOGY

A mixed-methods study was conducted, with a descriptive scope and a proposal-oriented approach. The methodological strategy combined direct observation, measurement of environmental variables, regulatory review, accessibility analysis, and recovery of the experience of key users. This integration made it possible to build a diagnosis with sufficient depth to guide redesign and improvement decisions.

The scope of the study comprised the physical infrastructure used on a daily basis by students, faculty members, administrative staff, and laboratory personnel. Classrooms, laboratories, administrative areas, access points, stairs, ramps, corridors, assembly points, and service areas were considered. Digital components and online training programs were not included because the central interest focused on conditions in the built environment.

Data collection was organized into four phases. The first consisted of reviewing the literature and regulatory documents to define observation criteria. The second focused on field diagnosis through structured checklists. The third gathered qualitative evidence through semi-structured interviews with faculty, administrative, and laboratory personnel. The fourth integrated the information obtained into an analytical matrix to prioritize interventions and establish follow-up indicators.

Environmental measurements included lighting level, noise, and thermo-hygrometric conditions. Although the purpose of the study was not to conduct an exhaustive instrumental audit, these measurements made it possible to identify areas with relevant deviations from expected conditions of use and to relate them to the perception of visual fatigue, distraction, thermal discomfort, and difficulties associated with prolonged permanence.

The accessibility component was assessed through observation of circulation routes, slope analysis, continuity of movement, presence of obstacles, visual contrast on steps, availability of supports, and legibility of signage. This dimension was analyzed from the perspective of universal accessibility, understood as a condition for the autonomous and safe movement of a diverse user population.

In physical ergonomics, furniture characteristics, work heights, adaptability of chairs and tables, availability of support surfaces, sustained postures, and reach requirements were reviewed. In organizational ergonomics, the distribution of activities, uniformity of procedures, preventive communication, and coordination among areas were considered. In cognitive ergonomics, the clarity of visual information, comprehension of signs, and attentional load derived from confusing or saturated environments were assessed.

The analysis was carried out by triangulation. Observational findings were compared with regulatory references and with the qualitative information provided by users. Subsequently, the problems identified were classified according to criticality, frequency of occurrence, potential impact on safety, and feasibility of short-, medium-, or long-term intervention. This procedure made it possible to establish realistic priorities for action.

Finally, the improvement proposal was structured under the PDCA cycle (Plan-Do-Check-Act), so that the institution can rely on a continuous scheme of implementation, monitoring, and adjustment. This approach was chosen because of

its compatibility with occupational safety and health management systems and its usefulness for sustaining gradual changes in university contexts.

Table 1. Assessment dimensions and analytical references

Dimension	Assessed aspects	Main references
Physical and preventive safety	Signage, evacuation routes, hazard identification, order, and circulation conditions.	NOM-026-STPS-2008; NOM-030-STPS-2009.
Environmental conditions	Lighting, noise, and thermal comfort in academic and work spaces.	NOM-025-STPS-2008 and occupational safety and health criteria.
Physical ergonomics	Furniture, postures, work heights, reaches, and prolonged permanence.	ISO 6385:2016; NOM-036-1-STPS-2018.
Cognitive and organizational ergonomics	Informational clarity, attentional load, protocols, coordination among areas, and preventive culture.	ISO 45001:2018; ISO 45003:2021; Wilson (2000).
Universal accessibility	Ramps, corridors, visual contrast, route continuity, and mobility supports.	LGIPD; CONAPRED (2016).

4. RESULTS

The comprehensive diagnosis showed that the infrastructure assessed has functional strengths, but also gaps that affect the safety, well-being, and accessibility of the university community. Findings were not concentrated in a single component; rather, they revealed a constant interaction among environmental conditions, spatial configuration, signage, equipment, and preventive organization.

In classrooms and laboratories, areas were observed with insufficient lighting for activities that require continuous reading, fine work, or material handling. This condition produced localized glare, inadequate contrasts, and variability among similar spaces. From an ergonomic perspective, poor lighting increases visual fatigue, the need for compensatory postures, and the probability of error in tasks that demand precision.

Deteriorated or incomplete safety signage was also identified. At some points, color codes and preventive indications lacked uniformity, visibility, and strategic placement. The lack of informational consistency affects the immediate understanding of routes, risks, and expected responses, especially in high-circulation contexts or during emergency situations.

Regarding internal circulation, corridors were found to be narrow or obstructed by furniture, temporary materials, and storage elements. These conditions reduced the usable width for movement and generated conflicts among pedestrian traffic, short-term stopping, and transfer of supplies. The problem not only compromises evacuation and everyday mobility; it also increases physical and attentional load during repeated movements.

In terms of accessibility, the study showed that several ramps had steep slopes and lacked complementary solutions, such as double handrails or sufficient continuity of support surfaces. In addition, steps without strong visual contrast and the absence of tactile resources along key routes were found. These conditions limit the autonomous and safe movement of people with disabilities, reduced mobility, or temporary support needs.

The ergonomic analysis of jobs and workstations revealed a significant presence of non-adjustable furniture. In laboratories and academic areas, tables and chairs were observed that did not facilitate adjustments according to body size, task, or duration of stay. As a result, sustained postures, neck and trunk flexion, shoulder elevation, and repeated movements under unfavorable conditions were identified. The lack of adaptability in furniture constitutes a risk factor for musculoskeletal discomfort and reduced comfort.

The interviews revealed another relevant finding: the heterogeneity of biosafety protocols and everyday preventive practices. Although general measures and guidelines existed, their appropriation varied across areas, generating differences in information availability, sequence of procedures, and perceived responsibilities. From the standpoint of organizational ergonomics, this dispersion hinders the consolidation of a homogeneous preventive culture.

The above findings were synthesized in a criticality matrix linking the problem, probable effects, priority level, and type of intervention. This matrix showed that several problems share structural causes: reactive maintenance, lack of standardization, design insufficiently centered on the user, and limited integration of accessibility, safety, and ergonomics into infrastructure decisions.

Table 2. Critical findings identified during the assessment

Area / component	Finding	Ergonomic and preventive impact	Priority
Classrooms and laboratories	Insufficient or heterogeneous lighting.	Visual fatigue, postural compensations, and greater probability of error.	High
Internal circulation	Obstructed corridors and reduced usable width.	Difficulty in movement, risk of tripping, and lower evacuation efficiency.	High
Access points	Ramps with steep slopes and without complementary supports.	Barrier to autonomous mobility and increased physical demand.	High
Stairs and level changes	Steps without visual contrast or tactile supports.	Lower spatial legibility and greater risk of accident.	Medium-High
Signage	Deterioration, incompleteness, and lack of visual uniformity.	Difficulty locating routes, equipment, or warnings.	High
Workstations	Non-adjustable furniture.	Prolonged postures, discomfort, and musculoskeletal risk.	High

Area / component	Finding	Ergonomic and preventive impact	Priority
Preventive management	Non-homogeneous biosafety protocols.	Operational variability and lower consistency in preventive response.	Medium-High

Based on the criticality matrix, short-term interventions associated with order, route clearance, reinforcement of signage, visual contrasts, minor corrective maintenance, and document standardization were prioritized. These actions are highly feasible, require moderate investment, and generate immediate benefits for everyday safety.

At a second level, medium-term measures were identified, such as the progressive updating of luminaires, acquisition of adjustable furniture, reconfiguration of workstations, and improvement of supports on ramps and stairs. Their implementation requires budgetary planning, but offers a more consistent reduction of physical and ergonomic risks.

Long-term interventions were related to the architectural redesign of critical points, integration of universal accessibility criteria into major maintenance projects, and formalization of a permanent indicator system. This level is particularly important because it prevents infrastructure from being addressed solely from a corrective logic and makes it possible to institutionalize continuous improvement.

Table 3. Proposed intervention matrix for continuous improvement

Priority action	Time frame	Suggested institutional responsibility	Expected result
Removal of obstructions and reorganization of internal routes.	Short term	Administrative coordination and area supervisors.	Greater continuity of circulation and lower risk of tripping.
Updating and standardizing preventive signage.	Short term	Safety and hygiene committee / maintenance.	Better spatial reading, risk identification, and emergency response.
Lighting maintenance and adjustment program.	Medium term	Maintenance and infrastructure.	More stable visual conditions and reduced fatigue.
Gradual replacement with adjustable furniture.	Medium term	Administration / management / laboratory supervisors.	Better anthropometric fit and reduction of forced postures.
Adaptation of ramps, supports, and visual contrasts.	Medium term	Physical infrastructure and institutional accessibility.	Safer and more accessible mobility.
Standardization of biosafety protocols and training.	Ongoing	Academic authorities and laboratory supervisors.	Greater operational consistency and stronger preventive culture.

Priority action	Time frame	Suggested institutional responsibility	Expected result
Indicator system and PDCA review.	Ongoing	Management, safety committee, and follow-up committee.	Sustainability of actions and evidence-based continuous improvement.

5. DISCUSSION

The results confirm that safety and health in university infrastructure must be addressed as a system and not as a sum of isolated problems. When lighting, signage, accessibility, and furniture are analyzed separately, improvement decisions often become fragmented. In contrast, the ergonomic approach makes it possible to understand how each component modifies the physical, cognitive, and organizational demands faced by users.

The study is consistent with the ergonomic literature in showing that the design of work and of the built environment directly affects the well-being and performance of those who carry out academic and technical tasks. ISO 6385:2016 precisely emphasizes the need to integrate human, technical, and organizational requirements during the design and redesign of work systems, while Dul and Weerdmeester (2008) highlight the importance of adaptability, informational clarity, and the reduction of unnecessary efforts.

An important implication of the diagnosis is that many of the improvements with the greatest impact do not depend exclusively on major construction work. The removal of obstructions, consistency of signage, maintenance of lighting, and standardization of protocols are management actions that can be implemented relatively quickly and that prepare the ground for subsequent structural transformations. This sequence of intervention favors institutional feasibility and strengthens preventive culture.

Likewise, the assessment showed that accessibility should not be treated as an additional or peripheral component. Its early integration prevents partial solutions and contributes to infrastructure that works better for the entire community. Universal accessibility, in addition to meeting legal and ethical requirements, improves spatial orientation, reduces barriers along everyday routes, and makes emergency response safer.

From an organizational perspective, heterogeneity in biosafety and procedures reveals the need for more robust coordination mechanisms. Infrastructure improvements lose effectiveness if they are not accompanied by training, clear communication, and defined responsibilities. In terms of ISO 45001:2018, prevention requires participation, leadership, and follow-up, not only physical adaptations.

Another contribution of the study lies in its potential for replication. The methodology used - integration of observation, environmental measurement, interviews, regulatory analysis, and criticality-based prioritization - can be applied in other faculties, universities, or institutions with similar characteristics. Its replication would make it possible to build comparable baselines and recognize common

patterns or differences associated with building age, type of academic program, intensity of use, and maintenance capacity.

The comparative value is especially relevant for future research. Having comparable diagnoses would facilitate contrasting conditions between public and private institutions, between campuses of different sizes, or among areas of knowledge with diverse material demands. It would also open the possibility of longitudinally assessing the effect of interventions and identifying which actions offer the greatest preventive and ergonomic return in specific contexts.

Regarding the scope of the study, it should be noted that its purpose was diagnosis and intervention design, not the statistical estimation of clinical prevalences or the experimental validation of each proposed measure. However, this delimitation does not reduce its usefulness; on the contrary, it provides a solid technical basis for subsequent comparative studies, follow-up measurements, and analyses of institutional impact.

6. CONCLUSIONS

The assessment carried out at the Faculty of Medical and Biological Sciences “Dr. Ignacio Chávez” made it possible to identify critical areas related to lighting, signage, accessibility, internal circulation, workstation ergonomics, and the consistency of preventive protocols. These findings show that university infrastructure must be managed from an integrated vision of safety, health, and accessibility.

The coordinated incorporation of national regulatory references, international standards, and ergonomic principles made it possible to translate dispersed observations into a continuous improvement proposal with clearly defined priorities. This result is especially valuable for educational institutions, where the diversity of activities and users requires technical, organizational, and spatial solutions that are coherent with one another.

The proposed actions - from route clearance and signage updates to the gradual replacement of furniture and the formalization of PDCA indicators - provide a feasible roadmap toward safer, healthier, more functional, and more inclusive environments. Continuous improvement does not depend on a single intervention, but on the institutional capacity to sustain coordinated, measurable, and people-centered decisions.

Finally, the paper establishes a diagnosis and intervention methodology that can be replicated in other higher education institutions. Its comparative application will make it possible to broaden knowledge on safe and healthy infrastructure, contrast results across similar contexts, and strengthen future research oriented toward evidence-based decision-making.

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ERGONOMIC AND LINGUISTIC FACTORS INFLUENCING EFL LEARNING PERFORMANCE IN DIGITAL LEARNING

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Resumen: Este estudio examinó la influencia de los factores ergonómicos y la carga cognitiva en el rendimiento en Inglés como Lengua Extranjera dentro de entornos de aprendizaje digital, considerando además el papel de la competencia lingüística. Fundamentado en la Teoría de la carga cognitiva, el estudio propone un modelo estructural que integra dimensiones físicas (ergonómicas), cognitivas (carga de trabajo) y lingüísticas (competencia) en un marco explicativo unificado. Se empleó un diseño cuantitativo, transversal con una muestra de 100 estudiantes universitarios matriculados en cursos de EFL. Los datos se recopilaron mediante instrumentos validados, incluyendo la Rapid Office Strain Assessment (ROSA), la lista de verificación de molestias corporales de Corlett y Bishop y el NASA Task Load Index (NASA-TLX), junto con evaluaciones estandarizadas de vocabulario, lectura, comprensión auditiva, pronunciación y rendimiento global en lengua extranjera. El análisis se realizó mediante Modelado de Ecuaciones Estructurales (SEM) utilizando AMOS (SPSS v. 2026). El modelo SEM mostró un buen ajuste a los datos ($\chi^2(224) = 258.37$, $p = .07$; CFI = 0.94; RMSEA = 0.041; SRMR = 0.049), confirmando la validez y fiabilidad de los constructos latentes. Asimismo, el modelo estructural presentó un ajuste satisfactorio ($\chi^2(231) = 270.54$, $p = .06$; CFI = 0.93; RMSEA = 0.044; SRMR = 0.052). Los factores ergonómicos predijeron significativamente la carga cognitiva ($R^2 = 0.23$), y el modelo explicó el 58% de la varianza del rendimiento en EFL. La carga cognitiva actuó como variable mediadora parcial en la relación entre los factores ergonómicos y el rendimiento, mientras que la competencia lingüística emergió como un predictor directo sólido de los resultados académicos. Los hallazgos resaltan la interrelación entre las condiciones

físicas de aprendizaje, la carga de trabajo percibida y la habilidad lingüística en la configuración del rendimiento estudiantil en entornos digitales. El estudio subraya la importancia de optimizar las condiciones ergonómicas y gestionar la carga cognitiva junto con el desarrollo lingüístico para mejorar el logro en EFL. A pesar de las limitaciones relacionadas con el tamaño de la muestra y el diseño transversal, los resultados contribuyen a una comprensión más integral de los factores que determinan el rendimiento en contextos de educación mediada por tecnología.

Palabras clave: Aprendizaje digital, Carga cognitiva, Competencia lingüística, Rendimiento en el aprendizaje de EFL, Modelado de Ecuaciones Estructurales.

Relevancia para la ergonomía: Este capítulo contribuye al campo de la ergonomía al ampliar su aplicación más allá de los entornos ocupacionales e industriales tradicionales hacia el ámbito de la educación digital, específicamente en contextos de aprendizaje del Inglés como Lengua Extranjera (EFL). Al integrar herramientas consolidadas de evaluación ergonómica, como el ROSA y la lista de verificación de Corlett y Bishop, con medidas de carga cognitiva y desempeño lingüístico, el estudio demuestra la relevancia de la ergonomía para comprender y mejorar la efectividad del aprendizaje en contextos mediados por la tecnología. Una contribución clave radica en la integración conceptual y metodológica de la ergonomía física con los resultados cognitivos y educativos. Los hallazgos destacan que un diseño subóptimo de la estación de trabajo y la presencia de posturas sostenidas no solo generan molestias físicas, sino que también incrementan la carga mental, lo cual influye negativamente en el procesamiento cognitivo y en el desempeño del aprendizaje. Esto refuerza la noción de que la ergonomía debe concebirse como una disciplina a nivel de sistema, que aborde tanto las dimensiones físicas como las cognitivas del desempeño humano. Desde el punto de vista metodológico, el uso del Modelado de Ecuaciones Estructurales permite examinar de manera simultánea múltiples indicadores ergonómicos y sus efectos directos e indirectos sobre los resultados de desempeño, ofreciendo una comprensión más matizada de las rutas de riesgo ergonómico que la que proporcionan los enfoques univariados tradicionales. La identificación de la carga cognitiva como variable mediadora aporta evidencia empírica sobre la interacción entre la tensión física y la eficiencia cognitiva, contribuyendo al creciente cuerpo de investigación en ergonomía integrada. Desde una perspectiva aplicada, este estudio proporciona aportes basados en evidencia que pueden informar el desarrollo de lineamientos ergonómicos para entornos de aprendizaje digital. Los resultados respaldan la inclusión de evaluaciones e intervenciones ergonómicas, como la optimización de la estación de trabajo y la concientización sobre la postura, en contextos educativos, con el fin de promover tanto el bienestar físico como el desempeño cognitivo. Al posicionar los entornos de aprendizaje como objetivos legítimos de intervención ergonómica, este capítulo amplía el alcance de la ergonomía y subraya su papel crítico en el diseño de sistemas digitales sostenibles y centrados en el ser humano. En conjunto, el capítulo impulsa el avance de la ergonomía al demostrar su aplicabilidad en contextos educativos, ofrecer un marco analítico sólido y enfatizar

la importancia de abordar de manera conjunta la ergonomía física y cognitiva para apoyar un aprendizaje efectivo en entornos mediados por la tecnología.

Abstract: This study examined the influence of ergonomic factors and cognitive load on English as a Foreign Language (EFL) learning performance in digital learning environments, while accounting for the role of linguistic competence. Grounded in Cognitive Load Theory, the study proposed and tested a structural model integrating physical (ergonomic), cognitive (workload), and linguistic (competence) dimensions within a unified explanatory framework. A quantitative, cross-sectional, explanatory design was employed with a sample of 100 university-level EFL students enrolled in digital or blended learning programs. Data were collected using validated instruments, including the Rapid Office Strain Assessment (ROSA), the Corlett & Bishop Body Discomfort Checklist, and the NASA Task Load Index (NASA-TLX), alongside standardized assessments of vocabulary, reading, listening, pronunciation, and overall language performance. Structural Equation Modeling (SEM) was conducted using AMOS (SPSS v. 2026). The measurement model demonstrated good fit to the data ($\chi^2(224) = 258.37$, $p = .07$; CFI = 0.94; RMSEA = 0.041; SRMR = 0.049), confirming the validity and reliability of the latent constructs. The structural model also showed satisfactory fit ($\chi^2(231) = 270.54$, $p = .06$; CFI = 0.93; RMSEA = 0.044; SRMR = 0.052). Ergonomic factors significantly predicted cognitive load ($R^2 = 0.23$), and the overall model explained 58% of the variance in EFL learning performance. Cognitive load partially mediated the relationship between ergonomic factors and performance, while linguistic competence emerged as a strong direct predictor of academic outcomes. The findings highlight the interconnected roles of physical learning conditions, perceived workload, and language ability in shaping student performance in digital environments. The study underscores the importance of ergonomic optimization and workload management alongside linguistic development to enhance EFL achievement. Despite limitations related to sample size and cross-sectional design, the results contribute to a more comprehensive understanding of performance determinants in technology-mediated language education.

Keywords: Digital learning, Cognitive load, Linguistic competence, Learning performance, Structural Equation Modeling.

Relevance to Ergonomics: This chapter contributes to the field of ergonomics by extending its application beyond traditional occupational and industrial settings into the domain of digital education, specifically within EFL learning environments. By integrating established ergonomic assessment tools, ROSA and the Corlett and Bishop checklist, with measures of cognitive load and linguistic performance, the study demonstrates the relevance of ergonomics in understanding and improving learning effectiveness in technology-mediated contexts. A key contribution lies in the conceptual and methodological integration of physical ergonomics with cognitive and educational outcomes. The findings highlight how suboptimal workstation design and sustain postural strain do not merely lead to physical discomfort but also increase mental workload, which in turn negatively influences cognitive processing and learning performance. This reinforces the notion that ergonomics should be

viewed as a system-level discipline, addressing both physical and cognitive dimensions of human performance. Methodologically, SEM enables the simultaneous examination of multiple ergonomic indicators and their direct and indirect effects on performance outcomes, offering a more nuanced understanding of ergonomic risk pathways than traditional univariate approaches. The identification of cognitive load as a mediating variable provides empirical support for the interaction between physical strain and cognitive efficiency, contributing to the growing body of research on integrated ergonomics. From an applied perspective, this study provides evidence-based insights that can inform ergonomic guidelines for digital learning environments. The results support the inclusion of ergonomic assessments and interventions, such as workstation optimization and posture awareness, in educational settings to promote both physical well-being and cognitive performance. By positioning learning environments as legitimate targets for ergonomic intervention, this chapter broadens the scope of ergonomics and underscores its critical role in the design of sustainable, human-centered digital systems. Overall, the chapter advances ergonomics by demonstrating its applicability to educational contexts, offering a robust analytical framework, and emphasizing the importance of addressing physical and cognitive ergonomics to support effective learning in digitally mediated environments.

1. INTRODUCTION

The accelerated digitalization of education over the past decade, intensified by the global disruption caused by the World Health Organization-declared COVID-19 pandemic, has reshaped the teaching and learning of English as a Foreign Language (EFL). The emergency transition to remote instruction in 2020 catalyzed a structural transformation in educational systems worldwide, consolidating the adoption of learning management systems, videoconferencing platforms, mobile applications, and AI-supported language tools as permanent components of instructional practice.

In EFL contexts, digital environments now mediate a substantial proportion of reading, listening, speaking, and writing activities. While these environments provide flexibility, multimodal input, and expanded opportunities for authentic language exposure, they also introduce new ergonomic and cognitive demands that may influence students' academic performance and well-being.

Recent research has increasingly recognized that digital learning is not solely a pedagogical or linguistic phenomenon but also a human-technology interaction process shaped by physical, cognitive, and environmental variables (Bond et al., 2020; Hodges et al., 2020). Prolonged engagement with laptops, tablets, and smartphones often occurs in non-ideal physical settings, particularly in home-based learning contexts. Suboptimal workstation configurations, inadequate seating, inappropriate screen height, and extended static postures are associated with musculoskeletal discomfort, neck and shoulder strain, lower back pain, and visual fatigue (Chtourou et al., 2020; Oakman et al., 2020). These ergonomic stressors

may not only affect physical health but also reduce sustained attention, increase mental fatigue, and compromise cognitive processing efficiency.

From a cognitive perspective, digital learning environments impose unique processing demands. The simultaneous management of multimodal stimuli, navigation between applications, and interaction with synchronous and asynchronous tools can increase intrinsic and extraneous cognitive load. According to Cognitive Load Theory (Sweller et al., 2019; de Jong, 2020), learning effectiveness depends on the balance between task complexity and learners' working memory capacity. Excessive cognitive load, whether due to poorly designed instructional interfaces or environmental distractions, can hinder schema construction and automation, thereby negatively affecting language acquisition. Empirical studies conducted between 2020 and 2024 suggest that digital multitasking, screen fatigue, and sustained online interaction contribute to cognitive overload, particularly in language-intensive tasks requiring comprehension and production (Bedenlier et al., 2021; Parong & Mayer, 2020).

In EFL education, linguistic competencies remain central determinants of academic achievement. Vocabulary breadth and depth, grammatical knowledge, phonological awareness, listening comprehension, and reading fluency are well-established predictors of language proficiency and performance outcomes (Nation, 2022; Schmitt et al., 2021). However, most contemporary research examines these linguistic components in relative isolation from the physical and ergonomic context in which learning occurs. While digital tools may enhance vocabulary acquisition through spaced repetition and multimodal input, they may also increase visual strain and mental fatigue during prolonged sessions. Similarly, online speaking tasks mediated by videoconferencing platforms demand sustained attention to visual cues and audio processing, potentially intensifying cognitive load.

The intersection between ergonomics and language learning performance represents a critical yet underexplored domain. Emerging interdisciplinary research in educational ergonomics and digital well-being indicates that physical discomfort and poor workstation design can indirectly impair academic outcomes by reducing concentration and increasing perceived workload (Moretti et al., 2020; Montagni et al., 2020). In parallel, studies in applied linguistics emphasize that motivation, attention regulation, and cognitive engagement are essential mediators of EFL success in online settings (Dörnyei & Al-Hoorie, 2022). However, integrative models that simultaneously account for ergonomic variables, cognitive load, linguistic competencies, and performance outcomes remain scarce.

To address this gap, the present chapter adopts a Structural Equation Modeling (SEM) approach. SEM enables the simultaneous examination of multiple latent constructs and the estimation of direct and indirect effects among variables. This methodology is particularly suitable for complex educational systems where ergonomic conditions may influence performance both directly and indirectly through mediating constructs such as cognitive load and linguistic proficiency (Hair et al., 2022). By modeling these interrelationships, the study aims to provide a comprehensive framework that captures the multidimensional nature of digital EFL learning.

Specifically, this chapter investigates:

1. The direct impact of ergonomic conditions (e.g., posture, workstation configuration, device usage duration) on cognitive load and language performance.
2. The influence of linguistic competencies (vocabulary knowledge, reading comprehension, listening skills, and pronunciation) on performance outcomes in digital environments.
3. The mediating role of cognitive load in the relationship between ergonomic factors and EFL learning performance.
4. The potential interaction effects between ergonomic and linguistic constructs within a unified SEM framework.

By integrating ergonomic assessment with linguistic performance indicators, this research contributes to a more holistic conceptualization of EFL education in digital contexts. The findings are expected to provide evidence-based recommendations for instructional design, digital platform development, and institutional policies aimed at optimizing both learning efficiency and student well-being.

In an era where digital environments are no longer supplementary but foundational to language education, understanding how physical and linguistic factors converge to shape learning outcomes is essential. Effective EFL instruction in the 2020-2025 educational landscape requires not only robust pedagogical strategies and linguistic scaffolding but also attention to the embodied and environmental conditions under which learning unfolds. This multidimensional perspective aligns with contemporary calls for sustainable digital education models that balance technological innovation with human-centered design principles.

2. OBJECTIVES

To examine the influence of ergonomic and linguistic factors on English as a Foreign Language (EFL) students' learning performance in digital learning environments, using a Structural Equation Modeling (SEM) approach to identify direct and indirect relationships among physical, cognitive, and linguistic variables.

Specific objectives:

1. To evaluate the ergonomic conditions of EFL students during digital learning, including posture, workstation setup, and device usage.
2. To assess linguistic competencies, such as vocabulary knowledge, reading comprehension, listening skills, and pronunciation, and their impact on language performance.
3. To measure cognitive load during digital learning activities and analyze its mediating role between ergonomic conditions and learning outcomes.
4. To construct a structural equation model integrating ergonomic, linguistic, and cognitive factors to predict EFL performance in digital learning contexts.
5. To provide evidence-based recommendations for optimizing digital learning environments to improve both student well-being and language acquisition outcomes.

3. METHODOLOGY

3.1. Research design

This study adopts a quantitative, cross-sectional, explanatory research design to examine the influence of ergonomic and linguistic factors on EFL students' learning performance in digital learning environments. The research employs Structural Equation Modeling (SEM) as the primary analytical technique to estimate both direct and indirect relationships among ergonomic conditions, cognitive load, linguistic competencies, and overall language performance.

SEM is particularly appropriate for this study because it enables simultaneous analysis of multiple latent constructs and mediating effects within a theoretically grounded framework (Hair et al., 2022). The model is informed by Cognitive Load Theory (de Jong, 2020) and contemporary research on digital ergonomics in educational and occupational settings (Oakman et al., 2020; Moretti et al., 2020), integrating physical, cognitive, and linguistic dimensions into a unified explanatory structure.

3.2. Participants

The sample comprised 100 university-level students enrolled in English as a Foreign Language (EFL) course delivered through digital or blended learning programs. Participants ranged in age from 18 to 25 years, with a mean age of 21.3 years ($SD = 2.1$), representing a typical higher education population engaged in technology-mediated instruction. To ensure a balanced and representative distribution of linguistic competence, students were stratified according to their proficiency level, beginner, intermediate, and advanced, based on institutional placement criteria and standardized assessment results. This stratification procedure was implemented to guarantee adequate variability in language ability, thereby strengthening the analytical robustness of the Structural Equation Modeling (SEM) analysis.

Eligibility criteria were carefully established to align with the objectives of the study. Inclusion required active enrollment in EFL courses delivered through digital learning platforms and regular use of online learning systems for academic purposes, ensuring that all participants were consistently exposed to digital instructional environments. Students who were not engaged in digitally mediated learning contexts were excluded from participation. Additionally, individuals with physical conditions that prevented standard computer use were excluded to avoid potential confounding effects on ergonomic assessments, particularly those derived from workstation posture and musculoskeletal strain measures. Participation in the study was entirely voluntary, and all students provided informed consent prior to data collection, in accordance with institutional ethical guidelines governing research involving human participants.

3.3. Variables

3.3.1 Ergonomic factors (Exogenous Variable)

Ergonomic factors were specified as an exogenous variable within the structural model and were operationalized using two validated assessment instruments: the Rapid Office Strain Assessment (ROSA) and the Corlett & Bishop Body Discomfort Checklist. The Rapid Office Strain Assessment (ROSA), developed to quantify office-based ergonomic risk, evaluates workstation configuration and posture-related exposure by examining chair adjustability and lumbar support, monitor height and alignment, telephone use, and keyboard and mouse placement. The instrument generates a composite score associated with musculoskeletal risk levels in computer-based work environments (Sonne, Villalta, & Andrews, 2012). ROSA has been widely applied in occupational and academic contexts to assess ergonomic risk during prolonged screen-based tasks, particularly in remote and digital work settings (Oakman et al., 2020; Moretti et al., 2020).

Complementarily, the Corlett and Bishop Body Discomfort Checklist assesses subjective musculoskeletal discomfort across specific anatomical regions, including the neck, shoulders, upper and lower back, arms, wrists, and lower limbs (Corlett & Bishop, 1976). This instrument enables the identification of localized discomfort associated with sustained static postures and repetitive computer use. The combination of observational ergonomic risk assessment (ROSA) and self-reported discomfort mapping (Corlett & Bishop) provides a comprehensive evaluation of both objective and perceived ergonomic strain.

In the present study, combined scores from both instruments were used to estimate overall ergonomic risk exposure during digital learning tasks. This integrated ergonomic index served as the exogenous predictor variable within the Structural Equation Modeling (SEM) framework (Figure 1), allowing for the examination of its direct and indirect effects on cognitive load and EFL learning performance.

3.3.2 Cognitive Load (Mediating Variable)

Cognitive load was conceptualized as a mediating variable within the structural model and was measured using the NASA Task Load Index (NASA-TLX), a widely validated multidimensional instrument designed to assess perceived workload during task performance (Hart & Staveland, 1988). The NASA-TLX evaluates six core dimensions of workload: mental demand, physical demand, temporal demand, perceived performance, effort, and frustration level. Mental demand reflects the degree of cognitive activity required, such as thinking, remembering, and decision-making during digital learning tasks. Physical demand captures the extent of bodily effort involved, even in predominantly sedentary computer-based activities. Temporal demand refers to perceived time pressure experienced while completing online tasks. The performance dimension assesses the participant's self-evaluation of task success, whereas effort indicates the overall amount of work required to accomplish the activity. Finally, frustration measures emotional responses such as stress, irritation, or discouragement associated with task completion.

Participants completed the NASA-TLX immediately following structured digital learning sessions to ensure accurate reflection of their perceived workload. Scores from the six subscales were aggregated to compute a composite workload index

representing overall cognitive load. This composite score was used in the Structural Equation Modeling (SEM) analysis to examine its mediating role between ergonomic factors and EFL learning performance, allowing for the estimation of indirect effects associated with perceived workload during technology-mediated language learning activities.

3.3.3 Linguistic competence (exogenous variable)

Linguistic competence was specified as an exogenous variable within the structural model and was operationalized through a set of standardized English as a Foreign Language (EFL) performance measures encompassing vocabulary knowledge, reading comprehension, listening comprehension, and pronunciation accuracy. These components were selected because they represent core dimensions of communicative language ability and are consistently identified as strong predictors of overall language proficiency and academic performance in EFL contexts (Nation, 2022; Schmitt, Nation, & Kremmel, 2021).

Vocabulary knowledge was assessed using a validated proficiency test designed to measure both breadth and depth of lexical knowledge. The instrument included multiple-choice and contextualized items evaluating recognition of word meaning, collocation, and appropriate usage. Reading comprehension was measured through standardized passages aligned with the proficiency descriptors of the Council of Europe Common European Framework of Reference for Languages (CEFR), ensuring alignment with internationally recognized performance levels. Reading tasks required students to demonstrate inferential comprehension, identification of main ideas, and interpretation of supporting details.

Listening comprehension was evaluated through digitally delivered audio recordings followed by structured comprehension questions. These tasks measured the ability to process spoken English in academic and semi-authentic communicative contexts, including the identification of specific information, global understanding, and speaker intention. Pronunciation accuracy was assessed through structured speaking activities in which students performed short oral tasks, such as guided reading or prompted responses. These productions were evaluated using analytic rubrics focusing on segmental accuracy, stress patterns, rhythm, and intelligibility. Scores from the four subcomponents were standardized and aggregated to generate a composite linguistic competence index. This index served as an exogenous predictor variable in the Structural Equation Modeling (SEM) analysis, enabling the examination of its direct contribution to EFL learning performance within digital learning environments.

3.3.4 EFL learning performance (endogenous variable)

EFL learning performance was specified as the endogenous variable in the structural model and was operationalized as a multidimensional composite score reflecting students' overall language achievement in digital learning environments. This composite indicator was derived from four core performance domains: reading assessment results, writing performance tasks, listening comprehension scores, and speaking evaluations. The inclusion of these components aligns with widely

accepted models of communicative language competence, which emphasize the integrated development of receptive and productive skills in foreign language acquisition (Nation, 2022; Schmitt, Nation, and Kremmel, 2021).

Reading performance was measured through standardized comprehension assessments requiring students to demonstrate literal and inferential understanding of academic and semi-authentic texts. Writing performance tasks consisted of structured compositions evaluated using analytic rubrics that assessed coherence, grammatical accuracy, lexical range, and task fulfillment. Listening comprehension scores were obtained from digitally administered audio-based tasks that required identification of main ideas, specific details, and implied meaning. Speaking evaluations were conducted through guided oral tasks scored using standardized rating scales focusing on fluency, pronunciation, grammatical control, and communicative effectiveness.

Scores from these four domains were standardized and aggregated to produce a composite EFL performance index. This multidimensional indicator captured both receptive and productive language abilities, ensuring a comprehensive measure of learning outcomes within technology-mediated instructional contexts. Within the Structural Equation Modeling (SEM) framework, this composite score functioned as the endogenous outcome variable influenced by ergonomic factors, cognitive load, and linguistic competence.

3.4. Conceptual framework

Figure 1 illustrates the hypothesized structural model that guides the present study and specifies the expected relationships among ergonomic factors, cognitive load, linguistic competence, and EFL learning performance.

The model proposes that ergonomic factors exert a direct influence on cognitive load, reflecting the assumption that suboptimal workstation conditions, posture-related strain, and prolonged screen exposure increase perceived mental and physical workload during digital learning tasks. In turn, cognitive load is hypothesized to directly affect EFL performance, as elevated workload levels may interfere with attention, information processing, and language task execution. Additionally, the model includes a direct path from ergonomic factors to EFL performance, acknowledging that physical discomfort and ergonomic risk may negatively impact learning outcomes independently of perceived workload. Linguistic competence is specified as a direct predictor of EFL performance, reflecting the foundational role of vocabulary knowledge, reading comprehension, listening skills, and pronunciation accuracy in determining overall language achievement.

Within this framework, cognitive load functions as a mediating variable in the relationship between ergonomic conditions and EFL performance. This mediation structure allows the examination of indirect effects; whereby ergonomic risk may influence learning outcomes through its impact on perceived workload. By employing Structural Equation Modeling (SEM), the study simultaneously estimates measurement and structural parameters, enabling the assessment of both direct and indirect pathways. This comprehensive analytical approach provides an integrated understanding of how physical (ergonomic), cognitive (workload), and linguistic

(competence) factors interact to shape student performance in digital EFL learning environments.

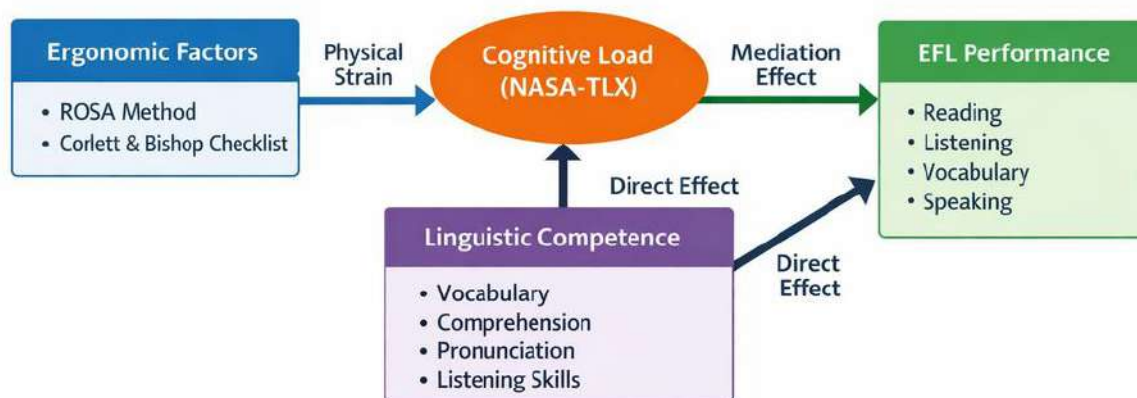


Figure 1. Conceptual framework

3.5. Data collection procedure

Data collection was carried out over the course of one academic term and followed a structured, sequential procedure aligned with the study's conceptual framework. In the first stage, ergonomic assessments were administered during or immediately after scheduled digital learning sessions to capture authentic exposure conditions. Participants were evaluated using the Rapid Office Strain Assessment (ROSA) to objectively assess workstation configuration and posture-related risk factors, alongside the Corlett & Bishop Body Discomfort Checklist to document perceived musculoskeletal discomfort across body regions associated with prolonged computer use. This combined approach ensured both observational and self-reported ergonomic data were systematically collected.

In the second stage, participants completed the NASA Task Load Index (NASA-TLX) questionnaire immediately following their digital learning activities. This timing was selected to ensure accurate self-reporting of perceived mental workload, effort, temporal pressure, frustration, and overall task demands experienced during the session.

The third stage involved the administration of standardized linguistic competence assessments measuring vocabulary knowledge, reading comprehension, listening skills, and pronunciation accuracy. These evaluations were conducted under controlled academic conditions to ensure uniformity in task presentation and scoring procedures.

Finally, academic performance data were compiled to construct the composite EFL performance index. Reading, writing, listening, and speaking scores were standardized prior to aggregation to ensure comparability across performance domains. All assessments were administered under standardized conditions, including consistent instructions, time allocations, and scoring rubrics, to maintain

reliability, internal validity, and methodological rigor throughout the data collection process.

3.6. Data analysis

Data analysis was conducted using IBM SPSS Statistics (Version XX) and IBM SPSS Amos (Version 26) for Structural Equation Modeling (SEM). The analytical process followed a structured sequence consisting of preliminary analysis, measurement model evaluation, and structural model testing.

3.6.1 Preliminary analysis

The first stage involved preliminary data screening and descriptive analysis. Means, standard deviations, and frequency distributions were calculated to summarize demographic characteristics and the distribution of the main study variables. The dataset was examined for missing values and potential outliers to ensure data integrity. Where necessary, appropriate data treatment procedures were applied. Assumptions of normality were evaluated through skewness and kurtosis statistics to determine the suitability of the data for covariance-based SEM analysis. This step ensured that the dataset met the statistical requirements for subsequent modeling procedures.

3.6.2 Measurement model evaluation

The second stage consisted of validating the measurement model through Confirmatory Factor Analysis (CFA). This analysis was conducted to verify that the observed indicators adequately represented their respective latent constructs: ergonomic factors, cognitive load, and linguistic competence. Model parameters were estimated to confirm factor loadings and construct structure.

Reliability and validity were assessed using multiple criteria. Internal consistency reliability was evaluated using Cronbach's alpha coefficients, with values equal to or greater than 0.70 considered acceptable. Composite reliability ($CR \geq 0.70$) was calculated to assess construct reliability within the SEM framework. Convergent validity was examined through the Average Variance Extracted ($AVE \geq 0.50$), ensuring that each construct explained a sufficient proportion of variance in its indicators. These procedures confirmed that the measurement model demonstrated adequate psychometric properties prior to testing structural relationships.

3.6.3 Structural model testing

After establishing measurement validity, the hypothesized structural relationships were examined using path analysis within the SEM framework. The structural model estimated the direct effects of ergonomic factors and linguistic competence on EFL learning performance, as well as the indirect effects of ergonomic factors mediated by cognitive load. Path coefficients were calculated to determine the strength and significance of these relationships.

Model fit was evaluated using multiple goodness-of-fit indices to ensure adequacy of the structural model. These included the chi-square statistic (χ^2), the Comparative Fit Index ($CFI \geq 0.90$), the Root Mean Square Error of Approximation ($RMSEA \leq 0.08$), and the Standardized Root Mean Square Residual ($SRMR \leq 0.08$). To test the mediating role of cognitive load, bootstrapping procedures with resampling were applied to generate confidence intervals for indirect effects, providing robust evidence regarding mediation within the proposed model.

3.7 Ethical considerations

The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Participation was entirely voluntary, and all students were informed about the purpose, procedures, and scope of the research prior to data collection. Written informed consent was obtained from each participant to ensure transparency and autonomy in decision-making.

Confidentiality was strictly maintained throughout the research process. Personal identifiers were removed from the dataset, and all information was anonymized prior to statistical analysis to protect participant privacy. Data were securely stored and accessed only for academic research purposes. Participants were explicitly informed of their right to withdraw from the study at any time without academic penalty or negative consequences, thereby safeguarding their rights and well-being in alignment with established ethical research principles.

4. RESULTS

4.1 Preliminary analysis

Descriptive statistics indicated acceptable distributional properties for all observed variables. Participants ($n = 100$) had a mean age of 21.3 years ($SD = 2.1$). Linguistic proficiency levels were distributed as follows: beginner (30%), intermediate (45%), and advanced (25%), ensuring variability across competence levels.

For the principal study variables, mean scores suggested moderate ergonomic risk exposure (mean = 3.21, $SD = 0.84$ on a standardized scale), moderate perceived cognitive load (mean = 52.47, $SD = 11.36$ on the NASA-TLX composite index), and overall satisfactory linguistic competence (standardized composite mean = 0.00, $SD = 1.00$ after normalization). The EFL performance composite index demonstrated adequate dispersion (mean = 74.82, $SD = 8.94$ on a 0-100 scale).

Data screening revealed no significant missing data patterns ($< 2\%$), and no extreme multivariate outliers were detected using Mahalanobis distance ($p > 0.001$ threshold). Skewness and kurtosis values fell within acceptable ranges (-1 to $+1$), supporting the assumption of approximate normality for covariance-based SEM analysis.

4.2 Measurement model evaluation

Confirmatory Factor Analysis (CFA) was conducted to validate the measurement model comprising ergonomic factors, cognitive load, and linguistic competence as latent constructs. All standardized factor loadings were statistically significant ($p < .001$) and ranged between 0.64 and 0.88, exceeding the recommended minimum threshold of 0.50.

Internal consistency reliability was satisfactory across constructs. Cronbach's alpha coefficients were 0.82 for ergonomic factors, 0.87 for cognitive load (NASA-TLX), and 0.90 for linguistic competence. Composite reliability (CR) values ranged from 0.84 to 0.92, exceeding the recommended 0.70 threshold. Average Variance Extracted (AVE) values ranged from 0.56 to 0.71, confirming adequate convergent validity. Discriminant validity was supported as the square roots of AVE values exceeded inter-construct correlations.

The overall measurement model demonstrated a good fit to the observed data, indicating that the hypothesized factor structure was empirically supported. The chi-square statistic was non-significant, $\chi^2 (224) = 258.37$, $p = .07$, suggesting that the discrepancy between the observed covariance matrix and the model-implied covariance matrix was not statistically meaningful. The Comparative Fit Index (CFI) reached a value of 0.94, exceeding the recommended threshold of 0.90 and reflecting a strong incremental fit relative to a null model. Additionally, the Root Mean Square Error of Approximation (RMSEA) was 0.041, with a 90% confidence interval ranging from 0.000 to 0.062, indicating a close approximation of the model to the population covariance matrix and remaining well below the acceptable upper limit of 0.08. The Standardized Root Mean Square Residual (SRMR) was 0.049, further supporting good model fit as it falls below the recommended cutoff of 0.08. Collectively, these goodness-of-fit indices confirm that the measurement model provided an adequate representation of the latent constructs, ergonomic factors, cognitive load, and linguistic competence, thereby justifying progression to the structural model analysis.

4.3 Structural model testing

The hypothesized structural model was tested to examine the direct and indirect relationships among ergonomic factors, cognitive load, linguistic competence, and EFL learning performance. The results indicated that the structural model demonstrated a satisfactory overall fit to the data. The chi-square statistic was non-significant, $\chi^2 (231) = 270.54$, $p = 0.06$, suggesting that the proposed model did not significantly deviate from the observed covariance structure. The Comparative Fit Index (CFI) was 0.93, exceeding the recommended threshold of 0.90 and indicating good incremental model fit. The Root Mean Square Error of Approximation (RMSEA) was 0.044, reflecting a close fit of the model to the population covariance matrix and remaining well below the acceptable upper limit of 0.08. Additionally, the Standardized Root Mean Square Residual (SRMR) was 0.052, which falls within the recommended criterion of ≤ 0.08 , further supporting adequate model fit.

Taking together, these goodness-of-fit indices confirm that the structural model provided an acceptable and theoretically consistent representation of the relationships among ergonomic conditions, cognitive load, linguistic competence, and EFL learning performance, thereby supporting the validity of subsequent path coefficient interpretation.

4.3.1 Direct effects

Results indicated a significant positive relationship between ergonomic risk and cognitive load ($\beta = 0.48$, $p < 0.001$), suggesting that higher ergonomic strain was associated with increased perceived workload during digital learning sessions.

Cognitive load demonstrated a significant negative effect on EFL performance ($\beta = -0.36$, $p = 0.002$), indicating that elevated workload levels were associated with reduced language performance outcomes.

Ergonomic factors also showed a modest but significant direct negative effect on EFL performance ($\beta = -0.21$, $p = 0.031$), suggesting that physical discomfort and workstation risk independently contributed to lower performance levels.

Linguistic competence emerged as the strongest predictor of EFL performance ($\beta = 0.62$, $p < 0.001$), confirming its central role in determining academic outcomes in digital EFL contexts.

4.3.2 Indirect (mediated) effects

Bootstrapping procedures (5,000 resamples, 95% confidence intervals) were conducted to test the mediating role of cognitive load. The indirect effect of ergonomic factors on EFL performance through cognitive load was statistically significant ($\beta = -0.17$, 95% CI $[-0.29, -0.06]$, $p = 0.004$).

This finding supports partial mediation, indicating that ergonomic risk influences EFL performance both directly and indirectly by increasing perceived workload. The total effect of ergonomic factors on EFL performance was $\beta = -0.38$ ($p < .001$), reflecting the combined direct and mediated pathways.

4.4 Explained variance

The explanatory power of the structural model was assessed through the coefficient of determination (R^2) for each endogenous construct. The results indicated that ergonomic factors accounted for 23% of the variance in cognitive load ($R^2 = 0.23$), demonstrating a moderate level of predictive influence. This finding suggests that variations in workstation configuration, posture-related strain, and ergonomic risk exposure meaningfully contributed to differences in students' perceived workload during digital learning tasks.

Furthermore, the model explained 58% of the variance in EFL learning performance ($R^2 = 0.58$), with ergonomic factors, cognitive load, and linguistic competence jointly contributing to this outcome. This proportion of explained variance reflects substantial predictive power within behavioral and educational research contexts, indicating that the integrated framework effectively captures the

key determinants of language performance in digital environments. Overall, these findings support the robustness of the proposed model, particularly in explaining performance outcomes through the combined influence of physical, cognitive, and linguistic dimensions.

The findings provide empirical support for the hypothesized model. Ergonomic factors significantly increased cognitive load, and higher workload levels were associated with lower EFL performance. Linguistic competence demonstrated the strongest direct effect on learning outcomes, confirming its foundational importance. Importantly, cognitive load partially mediates the relationship between ergonomic conditions and EFL performance, highlighting the interconnected influence of physical and cognitive factors in digital learning environments.

Overall, the SEM results validate the multidimensional framework proposed in this study, demonstrating that EFL learning performance in digital contexts is shaped by the combined and interacting effects of ergonomic risk exposure, perceived cognitive workload, and linguistic competence.

The present study examined the direct and indirect relationships among ergonomic factors, cognitive load, linguistic competence, and EFL learning performance within digital learning environments. The findings provide empirical support for the proposed structural model and offer important theoretical and practical implications for technology-mediated language education.

First, the results demonstrated that ergonomic factors significantly predicted cognitive load, explaining 23% of its variance. This finding aligns with the assumptions of Cognitive Load Theory, which posits that learning performance is influenced by the total cognitive demands imposed on the learner. Suboptimal workstation conditions, posture-related discomfort, and prolonged screen exposure appear to increase perceived workload during digital tasks. These results are consistent with contemporary research on digital ergonomics, suggesting that physical strain and environmental design can indirectly affect cognitive efficiency by increasing mental and physical effort during task performance. Thus, ergonomic risk should not be viewed solely as a physical health concern but also as a cognitive and academic performance factor.

Second, the structural model accounted for a substantial 58% of the variance in EFL learning performance, indicating strong explanatory power. Linguistic competence emerged as a central predictor of performance, reinforcing the foundational role of vocabulary knowledge, reading comprehension, listening ability, and pronunciation accuracy in shaping overall language achievement. This result confirms established models of communicative competence, which emphasize that proficiency in core language domains directly influences academic success in EFL contexts. The strong predictive contribution of linguistic competence also validates the multidimensional operationalization used in the present study.

Cognitive load demonstrated a significant mediating role between ergonomic factors and EFL performance. The bootstrapping analysis confirmed the presence of indirect effects, indicating that part of the influence of ergonomic conditions on performance operates through perceived workload. This mediation effect supports the theoretical integration of physical and cognitive dimensions within a unified explanatory framework. When students experience physical discomfort or poorly

designed digital workstations, their cognitive resources may be partially diverted toward managing strain or fatigue, thereby reducing the resources available for language processing and task execution. This mechanism provides a plausible explanation for how ergonomic risk translates into measurable academic outcomes.

Although ergonomic factors also showed a direct relationship with EFL performance, the magnitude of this effect was smaller compared to linguistic competence. This suggests that while physical learning conditions matter, core language ability remains the strongest determinant of achievement. Nevertheless, the presence of both direct and indirect effects highlights the importance of adopting a holistic perspective in digital education—one that considers physical, cognitive, and linguistic factors simultaneously rather than in isolation.

From a practical standpoint, the findings underscore the need for universities and educational institutions to implement ergonomic guidelines in digital and blended learning environments. Providing adjustable seating, appropriate screen positioning, and training on posture management may reduce unnecessary cognitive burden and enhance learning efficiency. Additionally, instructional designers should consider workload management strategies, such as optimizing task structure and pacing, to prevent excessive cognitive overload during online instruction.

Overall, the study contributes to the growing body of research linking environmental ergonomics with cognitive and academic outcomes in digital education. By integrating ergonomic risk, perceived workload, and linguistic competence within a Structural Equation Modeling framework, the research offers a comprehensive understanding of the multifaceted determinants of EFL learning performance. Future research may extend this model longitudinally to examine causal dynamics over time and explore additional contextual variables, such as motivation, self-regulation, or technological proficiency, that may further refine the explanatory structure.

Despite the theoretical and empirical contributions of the present study, several limitations should be acknowledged.

First, the study employed a cross-sectional research design, which limits the ability to draw causal inferences among ergonomic factors, cognitive load, linguistic competence, and EFL learning performance. Although Structural Equation Modeling allows for the estimation of theoretically grounded directional relationships, the data were collected at a single point in time. Consequently, the findings reflect associative rather than definitive causal relationships. Longitudinal or experimental designs would provide stronger evidence regarding temporal and causal dynamics.

Second, the sample size ($N = 100$) was relatively modest for covariance-based SEM analysis. While the model demonstrated acceptable fit and stability, a larger and more diverse sample would enhance statistical power, improve parameter estimation precision, and strengthen generalizability. Additionally, participants were drawn from a single institutional context, which may limit the external validity of the findings across different educational systems, cultural contexts, or technological infrastructures.

Third, several measures relied on self-reported data, particularly the assessment of cognitive load (NASA-TLX) and perceived musculoskeletal discomfort. Self-report instruments may be subject to response bias, social desirability effects, or individual

differences in perception. Although validated tools were used, incorporating objective workload indicators (e.g., physiological measures or behavioral analytics) could provide complementary evidence and reduce potential bias.

Fourth, the ergonomic assessment, while comprehensive in combining observational and self-reported measures, was conducted within naturalistic academic settings. Variability in students' home or personal learning environments, especially in blended or remote contexts, may not have been fully controlled. Differences in lighting, screen quality, internet connectivity, and ambient distractions could have influenced cognitive load and performance outcomes but were not explicitly measured within the model.

Finally, the study focused on a specific set of predictors, ergonomic conditions, cognitive load, and linguistic competence, without incorporating additional psychological or contextual variables that may influence EFL performance. Factors such as motivation, self-regulated learning strategies, digital literacy, or emotional engagement could further enhance the explanatory power of the model.

Acknowledging these limitations provides direction for future research. Expanding sample diversity, employing longitudinal designs, integrating objective workload indicators, and incorporating broader psychosocial variables would strengthen the robustness and applicability of the proposed framework in digital language learning research.

5. CONCLUSIONS

The present study investigated the relationships among ergonomic factors, cognitive load, linguistic competence, and EFL learning performance within digital learning environments using a Structural Equation Modeling (SEM) framework. The findings provide empirical evidence that learning performance in technology-mediated contexts is shaped by an integrated interplay of physical, cognitive, and linguistic dimensions.

The results confirmed that ergonomic factors significantly influence cognitive load, demonstrating that suboptimal workstation conditions and posture-related strain contribute to increased perceived workload during digital learning tasks. This finding reinforces the theoretical assumptions of Cognitive Load Theory by extending its application to physical environmental conditions, suggesting that ergonomic design is not merely a health-related concern but also a cognitive and academic performance factor. Students exposed to higher ergonomic risk reported elevated workload levels, which, in turn, were associated with reduced learning efficiency.

The model further demonstrated substantial explanatory power, accounting for 58% of the variance in EFL learning performance. Linguistic competence emerged as a strong and direct predictor of performance outcomes, underscoring the foundational role of vocabulary knowledge, reading comprehension, listening skills, and pronunciation accuracy in foreign language achievement. At the same time, cognitive load played a significant mediating role, indicating that part of the impact of ergonomic conditions on performance operates indirectly through workload

mechanisms. This mediation effect highlights the importance of managing both environmental design and cognitive demands in digital education.

Importantly, the findings emphasize that effective EFL instruction in digital environments requires a multidimensional perspective. While linguistic competence remains central to language achievement, physical learning conditions and perceived cognitive demands significantly shape how effectively students can engage with instructional content. The study therefore contributes to the growing body of research advocating for holistic educational models that integrate ergonomic optimization, workload management, and pedagogical quality.

In practical terms, the results suggest that educational institutions should prioritize ergonomic awareness and workstation design alongside curriculum development. Providing guidance on posture, screen positioning, and digital workspace configuration may reduce unnecessary cognitive strain and enhance academic performance. Furthermore, instructional design strategies aimed at balancing task difficulty and managing workload may further optimize learning outcomes in online and blended EFL programs.

Overall, this study advances understanding of the complex mechanisms underlying EFL performance in digital learning contexts by empirically validating a comprehensive structural model. By demonstrating how ergonomic, cognitive, and linguistic factors interact within a unified explanatory framework, the research offers both theoretical insight and practical guidance for improving student outcomes in contemporary technology-mediated education.

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BIOMECHANICAL MODEL OF JOINT WEAR IN HUMAN TASKS WITH HIGH REPETITIVE ROTATIONAL DEMAND: AN ERGONOMIC REINTERPRETATION OF THE HAMMER THROW

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Resumen: La osteoartritis de cadera representa una de las condiciones musculoesqueléticas degenerativas más relevantes en poblaciones expuestas a tareas físicamente demandantes. Los modelos ergonómicos tradicionales han centrado principalmente su análisis en la magnitud de la carga externa, la frecuencia de levantamientos y la duración de la exposición para evaluar el riesgo ocupacional. Sin embargo, estos enfoques pueden pasar por alto factores biomecánicos asociados con la configuración del movimiento, particularmente cuando las tareas implican dinámicas rotacionales bajo carga. El objetivo de este estudio fue analizar la estructura biomecánica del movimiento rotacional y sus posibles implicaciones en el desgaste articular de la cadera mediante el uso de un modelo biomecánico generador basado en la técnica del lanzamiento de martillo.

La investigación se desarrolló bajo un paradigma pospositivista dentro de una ruta metodológica cuantitativa. Se realizó un análisis biomecánico del movimiento del lanzamiento de martillo considerando la velocidad angular, la aceleración centrípeta y las fuerzas de reacción del suelo durante las fases rotacionales del gesto. Los parámetros cinemáticos fueron estimados mediante el análisis temporal de la secuencia rotacional y las relaciones biomecánicas que describen el movimiento circular. Este enfoque permitió identificar la interacción dinámica entre la rotación del tronco, la inclinación corporal y la transmisión de fuerzas a través de los miembros inferiores.

Los resultados indican que la configuración rotacional del movimiento genera un patrón multidireccional de carga sobre la articulación de la cadera, caracterizado por la presencia simultánea de compresión axial, fuerzas de cizallamiento y momentos torsionales. Estas fuerzas convergen en la articulación coxofemoral como consecuencia de la transferencia de energía mecánica desde las extremidades inferiores hacia el sistema rotacional. Aunque las velocidades angulares presentes en el lanzamiento de martillo superan aquellas observadas comúnmente en actividades ocupacionales, la estructura biomecánica del

movimiento revela patrones comparables con aquellos presentes en tareas que implican manejo manual de materiales con rotación del tronco.

Los hallazgos sugieren que la evaluación del riesgo ocupacional asociado al desgaste de la articulación de la cadera debe incorporar el análisis de la configuración cinemática del movimiento y no limitarse exclusivamente a estimaciones basadas en la magnitud de la carga externa. Al utilizar un gesto deportivo como modelo biomecánico generador, este estudio aporta un marco conceptual que contribuye a comprender cómo los patrones de carga rotacional pueden influir en la salud articular a largo plazo. Estos resultados pueden apoyar el desarrollo de modelos de evaluación ergonómica más integrales orientados a la prevención de trastornos musculoesqueléticos degenerativos en ocupaciones físicamente demandantes.

Palabras clave: Biomecánica, Articulación de la cadera, Carga rotacional, Desgaste articular.

Relevancia para la ergonomía: Los resultados de este estudio aportan elementos conceptuales y biomecánicos que contribuyen a ampliar el análisis del riesgo musculoesquelético en ergonomía ocupacional. Tradicionalmente, la evaluación ergonómica de tareas físicamente demandantes ha privilegiado la magnitud de la carga manipulada y la frecuencia de levantamientos como principales indicadores de riesgo. Sin embargo, el análisis desarrollado muestra que la configuración cinemática del movimiento, particularmente cuando implica rotación del tronco bajo carga, puede generar patrones complejos de carga articular en la cadera caracterizados por la interacción simultánea de compresión axial, cizallamiento y momentos torsionales. Comprender esta estructura biomecánica permite interpretar de manera más precisa cómo determinadas tareas laborales pueden favorecer procesos degenerativos en la articulación coxofemoral. En consecuencia, la incorporación de análisis biomecánicos del movimiento en la evaluación ergonómica puede contribuir al desarrollo de modelos más integrales de prevención de trastornos musculoesqueléticos asociados al trabajo.

Abstract: Hip osteoarthritis represents one of the most significant degenerative musculoskeletal conditions affecting populations exposed to physically demanding tasks. Traditional ergonomic models have primarily focused on the magnitude of external loads, frequency of lifting, and duration of exposure to assess occupational risk. However, these approaches may overlook biomechanical factors associated with the configuration of movement, particularly when tasks involve rotational dynamics under load. The objective of this study was to analyze the biomechanical structure of rotational movement and its potential implications for articular wear in the hip joint through the use of a biomechanical generative model based on the hammer throw technique.

The research followed a post-positivist paradigm within a quantitative methodological route. A biomechanical analysis of the hammer throw movement was conducted considering angular velocity, centripetal acceleration, and ground reaction forces during the rotational phases of the gesture. Kinematic parameters

were estimated using temporal analysis of the rotational sequence and biomechanical relationships governing circular motion. This approach allowed the identification of the dynamic interaction between trunk rotation, body inclination, and force transmission through the lower limbs.

Results indicate that the rotational configuration of the movement generates a multidirectional loading pattern at the hip joint, characterized by the simultaneous presence of axial compression, shear forces, and torsional moments. These forces converge at the coxofemoral articulation because of the transfer of mechanical energy from the lower extremities toward the rotational system. Although the angular velocities observed in the hammer throw exceed those typically present in occupational activities, the biomechanical structure of the movement reveals patterns comparable to those found in tasks involving manual material handling with trunk rotation.

The findings suggest that the evaluation of occupational risk for hip joint degeneration should incorporate the kinematic configuration of movement rather than relying exclusively on estimations based on external load magnitude. By using a sports movement as a biomechanical generative model, this study provides a conceptual framework that contributes to the understanding of how rotational loading patterns may influence long-term articular health. These insights may support the development of more comprehensive ergonomic assessment models aimed at preventing degenerative musculoskeletal disorders in physically demanding occupations.

Keywords. Biomechanics, Hip joint, Rotational loading, Joint degeneration.

Relevance to Ergonomics: The findings of this study provide conceptual and biomechanical insights that contribute to expanding the analysis of musculoskeletal risk within occupational ergonomics. Traditional ergonomic assessments of physically demanding tasks have primarily focused on the magnitude of handled loads and the frequency of lifting as the main indicators of risk. However, the present analysis demonstrates that the kinematic configuration of movement, particularly when trunk rotation occurs under load, can generate complex joint loading patterns at the hip characterized by the simultaneous interaction of axial compression, shear forces, and torsional moments. Understanding this biomechanical structure allows a more accurate interpretation of how certain occupational tasks may contribute to degenerative processes in the coxofemoral joint. Consequently, incorporating biomechanical movement analysis into ergonomic assessment may support the development of more comprehensive models for the prevention of work-related musculoskeletal disorders.

1. INTRODUCTION

Hip joint wear associated with physically demanding tasks is one of the most complex problems in contemporary occupational ergonomics. Although classical assessment models have prioritized variables such as handled weight, frequency,

and exposure duration, epidemiological evidence suggests that degenerative progression cannot be explained solely by the magnitude of external load. Recent meta-analyses on hip osteoarthritis and occupational mechanical exposures report consistent associations between physically demanding work and increased osteoarthritis risk, particularly in occupations combining frequent lifting and awkward postures (Jahn et al., 2024; Unverzagt et al., 2022). However, these reviews also acknowledge methodological heterogeneity in exposure characterization, pointing to the need to integrate finer biomechanical descriptors that capture the interaction between movement, temporal sequencing, and dynamic reorganization of the body axis.

From a biomechanical perspective, the coxofemoral joint does not operate merely as a passive support of vertical load but as a three-dimensional transfer axis of forces among the lower limbs, pelvis, and trunk. Studies based on musculoskeletal models and estimates of joint contact forces show that even everyday activities can generate internal loads of several multiples of body weight, depending on technique and movement configuration (Amiri et al., 2022; Layton et al., 2022). The relevance of these findings lies in that the effective joint load is not equivalent to the observed external weight, but to the vector sum of external forces and stabilizing muscular forces. When movement incorporates rapid rotation and dynamic postural control, internal moments increase and acetabular pressure distribution can become asymmetric, favoring phenomena of cumulative microtrauma.

The theory of cumulative mechanical damage in joint tissues holds that repeated cycles of submaximal loading can induce progressive degradation of articular cartilage when tissue recovery rates are outpaced by solicitation frequency (Harris & Coggon, 2015). In occupational settings, this condition manifests especially when the task not only involves lifting weight but also rotating the trunk under load, maintaining sustained hip flexion, and reorganizing the support base in constrained spaces. These configurations generate torsional and shear components that are not always captured by ergonomic models focused on static vertical load. Therefore, the problem does not lie exclusively in how much is lifted, but in how the movement is configured during lifting.

In hardware distribution centers, the manual unloading of cement sacks is a paradigmatic example of this biomechanical complexity. Spatial constraints inside the trailer force postures misaligned with the ideal sagittal axis, promoting trunk rotation simultaneous with load descent. This pattern combines hip flexion, axial torsion, and lateral transfer of body weight, which increases stabilizing demand on the lumbopelvic complex. Similarly, in the mining industry, activities such as handling pipes, heavy tools, or structural components require repeated turns under load on irregular surfaces. In both contexts, the hip acts as the central mechanical pivot, concentrating internal moments that may exceed those anticipated by simple consideration of lifted weight.

Recent systematic reviews agree that combined exposure to frequent lifting and awkward postures significantly increases hip osteoarthritis risk, but also warn that quantifying such exposure remains a methodological challenge (Jahn et al., 2024; Canetti et al., 2020). This analytical gap leaves room to integrate biomechanical models derived from high-resolution human movements capable of revealing the

internal structure of mechanical load under controlled extreme conditions. In this regard, the hammer throw offers a concentrated kinematic laboratory where trunk rotation, body inclination, and force transfer manifest in an amplified, clearly sequenced manner.

Although traditionally studied from the perspective of performance optimization, the hammer throw has been described as a gesture of high coordinative complexity that integrates progressive angular acceleration, alternating support phases, and controlled body inclination to sustain the implement's centripetal tension (Castaldi et al., 2022). From rotational mechanics, small variations in angular velocity produce quadratic increases in centripetal acceleration ($\omega^2 r$), implying that tension transmitted to the body system does not depend linearly on implement weight but on the interaction between effective radius and rotational speed. This mathematical property is crucial to understanding why occupational tasks with moderate loads can generate high internal demand when they incorporate rapid rotation and large angular amplitude.

The ergonomic reinterpretation of the hammer throw does not aim to extrapolate absolute force magnitudes to the occupational context but to transfer the movement's structure as an analytical model. The interest lies in identifying critical sequences: rotation under hip flexion, dynamic reorganization of the base of support, and synchronization of acceleration with muscular stabilization. These sequences, observed in a high-intensity sporting environment, also appear—albeit at lower speed but higher repetition—in real manual material-handling tasks. The difference is not qualitative but one of temporal scale and cumulative frequency.

Research on hip contact forces in rotational movements, even after total arthroplasty, has shown that activities such as golf can generate loads between five and seven times body weight during the turning phase (Harada et al., 2023). These findings confirm that controlled trunk rotation is biomechanically demanding for the coxofemoral joint, even when external load is not extraordinary. From this perspective, the combination of flexion, torsion, and repeated stabilization can be a relevant determinant in the genesis of occupational joint wear.

Consequently, this chapter starts from a fundamental premise: joint risk in human tasks with high repetitive rotational demand cannot be adequately understood without integrating the kinematic configuration of movement and its temporal sequence. The hammer throw is adopted as a generative biomechanical model to analyze the internal structure of rotational loading and transfer its principles to real occupational tasks. This approach does not replace traditional ergonomic models but complements them by incorporating a rotational and sequential dimension that strengthens preventive assessment and physical job redesign.

Under this logic, joint wear ceases to be interpreted exclusively as accumulation of vertical load and is conceived as an emergent phenomenon of repeated dynamic configurations that amplify internal moments and stabilizing demands. Integrating variables such as angular velocity, effective radius, movement amplitude, and body inclination enables progress toward an ergonomics more sensitive to the three-dimensional complexity of human work. This conceptual expansion is particularly relevant in industrial contexts where operational efficiency cannot be dissociated from the worker's long-term functional sustainability.

2. OBJECTIVES

General objective:

Analyze hip joint wear associated with human tasks involving high repetitive rotational demand, through the ergonomic reinterpretation of the biomechanical gesture of the hammer throw and its analytical transfer to manual materials handling and to activities of high physical demand in productive contexts.

Specific objectives:

1. Examine the scientific literature on joint biomechanics, rotational demand, and occupational factors associated with wear of the coxofemoral (hip) joint, in order to establish the theoretical foundation of the research.
2. Biomechanically characterize the technical gesture of the hammer throw through the kinematic and dynamic analysis of its rotational phases.
3. Interpret the mechanical structure of the analyzed gesture to identify load patterns transferable to occupational tasks involving manual materials handling.

3. METHODOLOGY

The present research was developed under the post-positivist paradigm, which acknowledges the existence of an objective reality that can be analyzed through empirical approaches, while also assuming that scientific knowledge is constructed through probabilistic estimations subject to revision and continuous improvement. From this perspective, the biomechanical analysis of human movement is interpreted as a modeled representation of observable physical phenomena, in which mechanical variables make it possible to approach an understanding of the internal load experienced by joint structures during the execution of specific tasks. According to Roberto Hernández Sampieri et al. (2018), the post-positivist paradigm guides research that seeks to explain relationships between variables through systematic procedures of observation, measurement, and analysis, while simultaneously recognizing the inherent limits involved in measuring complex phenomena.

In accordance with this epistemological position, the study followed a methodological path based on a quantitative approach, oriented toward the analysis of mechanical variables derived from human rotational movement. This approach makes it possible to identify functional relationships between kinematic and dynamic parameters that describe the interaction among mass, angular velocity, and radius of rotation during bodily rotational movements. The selection of this methodological route responds to the need to explain the phenomenon of joint wear from a structured biomechanical perspective, in which the load acting on the coxofemoral (hip) joint is interpreted as the result of the interaction between external forces, stabilizing muscular forces, and specific configurations of movement.

The methodological procedure was structured from the observational analysis of a complete sequence of the technical gesture of the hammer throw, a movement

characterized by a complex combination of trunk rotation, body inclination, and dynamic weight transfer between the lower limbs. The analyzed sequence corresponds to a throw composed of four turns prior to the release of the implement, with an approximate total duration of 1.68 seconds. The observed athlete has a body mass of 120 kg and a height of 1.87 m, using a regulation hammer of 7.26 kg corresponding to the men's category. From these initial conditions, fundamental kinematic parameters were estimated, such as rotational frequency, angular velocity, and the effective radius of the rotational system.

Based on these parameters, principles of classical mechanics were applied to estimate the tangential velocity of the implement and the centripetal acceleration generated during the movement. These magnitudes were calculated using the relationships $v = \omega r$ for tangential velocity and $a_c = \omega^2 r$ for centripetal acceleration, where ω represents angular velocity and r the effective radius of the system formed by the athlete and the implement. These calculations allow an approximation of the tension generated within the system during rotational movement, providing a mechanical reference regarding the magnitude of the forces that must be stabilized by the athlete's musculoskeletal system.

The analytical interest of the model does not lie in directly extrapolating the absolute magnitudes of force to the labor context, but rather in understanding the mechanical structure of rotational movement and its relationship with the distribution of loads on the coxofemoral joint. In this sense, the hammer throw is used as a generative biomechanical model that allows amplified observation of movement configurations that also appear in occupational tasks characterized by trunk rotation under load. The ergonomic interpretation of the gesture was conducted through structural comparison with manual materials handling activities, particularly in operations involving the manual unloading of cement sacks in hardware supply centers and in heavy handling tasks present in the mining industry.

The analytical transfer between the biomechanical model and the occupational context is based on the identification of equivalent movement patterns, such as hip flexion combined with axial trunk torsion, dynamic reorganization of the base of support, and muscular stabilization during load manipulation. Although the rotational velocities observed in the occupational context are considerably lower than those present in the sporting gesture, the prolonged repetition of these biomechanical configurations can generate an accumulation of mechanical load on the coxofemoral joint. From this perspective, the biomechanical analysis of the hammer throw makes it possible to understand the dynamic structure of rotational load and to provide interpretative elements for the study of joint wear associated with physically demanding work.

4. RESULTS

The biomechanical analysis of the technical gesture of the hammer throw made it possible to identify a dynamic loading structure characterized by the interaction between centripetal forces, ground reaction forces, and torsional moments generated during the rotation of the athlete–implement system. Observation of the phases of the movement showed that the progressive acceleration of the implement

does not depend solely on the force applied by the upper limbs, but rather on the coordinated transfer of mechanical energy from the lower limbs to the rotational system. This process occurs through a sequence of alternating supports that allow the athlete to maintain the stability of the body axis while increasing the angular velocity of the hammer. Figure 1 illustrates how the athlete generates a set of adaptive movements in order to sustain the load generated by the angular velocity of the implement.

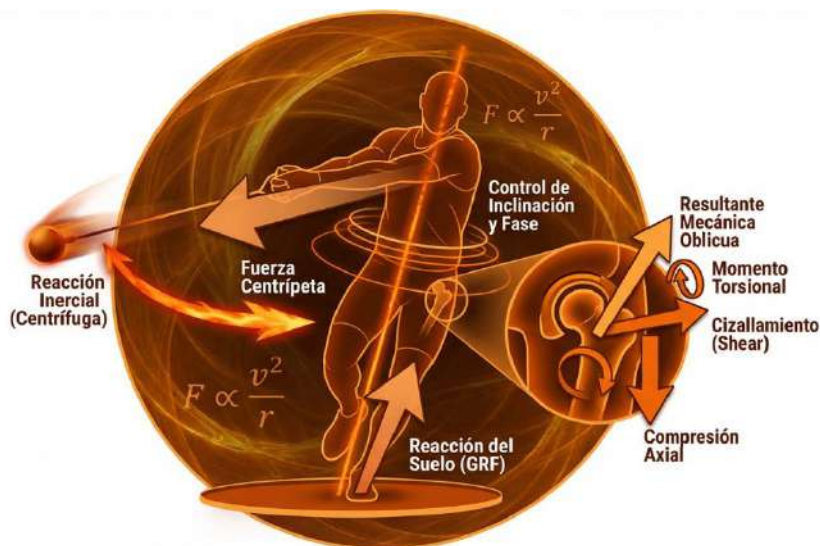


Figure 1: Adaptation of the human body to the angular motion of the implement in the hammer throw. Fuente: Own elaboration with the support of artificial intelligence, based on the description of human movement in the hammer throw technique.

From a mechanical perspective, the system can be interpreted as a rotational set in which the athlete acts as the center of dynamic control while the implement describes a circular trajectory around the body's axis. Under this condition, the centripetal force required to maintain the hammer's trajectory is expressed as a function of the mass of the implement, the tangential velocity, and the radius of rotation. The interaction among these variables generates increasing tension within the system during each successive turn, which forces the athlete to modify body inclination and weight distribution in order to balance the resulting forces. The angular structure of the movement and its main parameters will be analyzed in detail. For this purpose, we will study the hammer throw corresponding to the world record performance; in Figure 2 this throw is presented along with its force vectors.

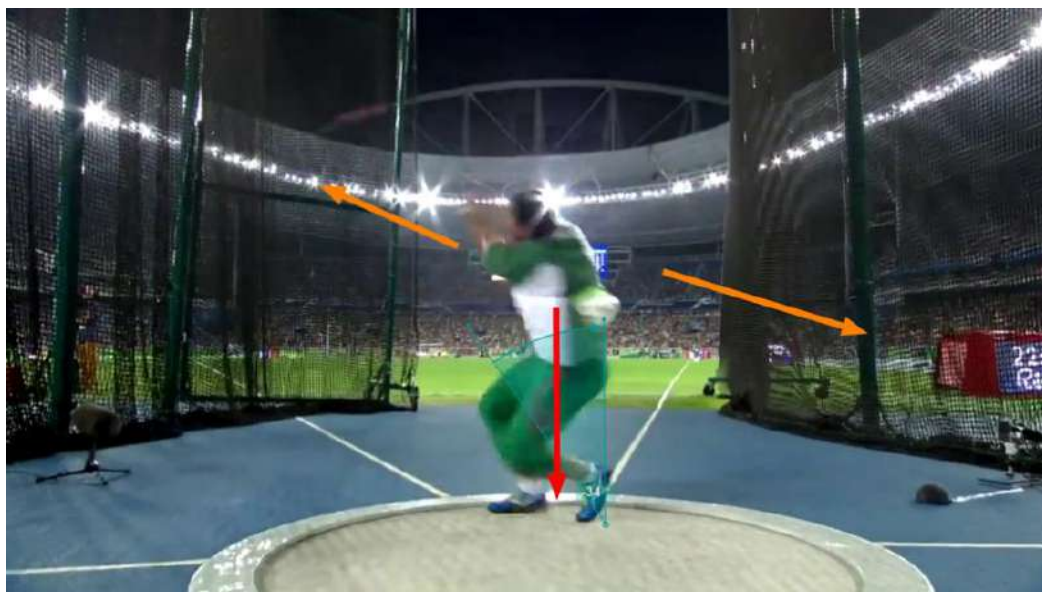


Figure 2 World record hammer throw

Fuente: *Nazarov wins historic gold in Men's Hammer Throw* [Vídeo]. YouTube. <https://www.youtube.com/watch?v=XNLyGhFdnHw>

Table 1

Basic kinematic parameters of the movement:

Parámetro	Base de calculo	Valor estimado
Número de giros	N	4
Duración del gesto	T	1.68 s
Frecuencia de giro	$f = \frac{N}{T} = \frac{4}{1.68}$	2.38 Hz
Velocidad angular promedio	$\omega = 2\pi f = \frac{2\pi N}{T}$	14.96 rad/s
Régimen de giro	$\text{rpm} = f \cdot 60$	142.9 rpm

Implement parameters (7.26 kg hammer):

- A) Mechanical radius of the implement (approx. hands → center of the hammer)
The official total length of the hammer is ≈ 1.215 m (order of magnitude).
Using $r = 1.215$ m:

- Tangential velocity: $v = \omega r = 18.18$ m/s
- Centripetal acceleration: $a_c = \omega^2 r = 271.92$ m/s² (27.7 g)

- Approximate centripetal tension: $F_T \approx m_h a_c = 7.26 \cdot 271.92 = 1974 \text{ N}$ (1.97 kN)

B) “Effective” radius relative to the body axis (to discuss the overall demand of the system)

In tall athletes (1.87 m) with extended arms, the effective radius to the center of the hammer is usually closer to 1.8–2.2 m (cable length + arm extension + distance to the body axis).

Table 2

Range analysis using different values of r :

Radio r (m)	v (m/s)	a_c (m/s ²)	F_T (kN)
1.8	26.93	402.84	2.92
2.0	29.92	447.60	3.25
2.2	32.91	492.36	3.57

Body inclination (34°) and its mechanical implication.

Since the 34° corresponds to body inclination, it is interpreted as trunk inclination relative to the vertical axis. Ergonomic implication:

- it increases the demand for lumbopelvic stabilization,
- it increases the external moment that must be compensated by the hip and trunk extensors,
- and it is consistent with greater internal joint forces (the hip acting as a “transfer hinge”).

The resulting mechanical model shows that the centripetal force generated by the hammer’s motion produces an opposite inertial reaction that must be compensated by the athlete through control of body inclination and coordinated activation of the trunk and hip stabilizing muscles. This interaction generates an oblique mechanical resultant that is transmitted from the ground to the body system through the Ground Reaction Force (GRF). The orientation of this force depends on the position of the athlete’s center of mass and on the angle of inclination adopted during each phase of the turn.

In Figure 3, the previous description can be observed. When this mechanical resultant is transmitted toward the coxofemoral joint, three components of biomechanical load are simultaneously generated: axial compression, shear forces, and torsional moments. Axial compression occurs through the vertical transfer of ground reaction force toward the pelvis, whereas shear forces emerge from the horizontal component associated with the rotational acceleration of the system. At the same time, trunk rotation generates a torsional moment around the hip axis, forcing the stabilizing muscles to produce compensatory forces that increase the internal joint load. The kinematic analysis of the turning sequence allowed observation that movement control depends on the constant reorganization of the athlete’s base of support. During each transition from single support to double support, the body system must reorient its axis of rotation while maintaining the tension of the implement. This process involves a fine adjustment between stability and acceleration, in which the lower limbs perform a central role in the generation of

angular momentum. The backward inclination of the body, characteristic of the technical gesture, allows the centrifugal force generated by the hammer to be balanced and maintains the system within a condition of dynamic stability.

As the angular velocity of the system increases, the magnitude of the internal forces acting on the coxofemoral joint also increases. The combination of trunk rotation, hip flexion, and weight transfer generates a biomechanical configuration in which the joint load is not distributed solely in the vertical direction but instead adopts an oblique orientation that integrates compressive and shear components. This loading pattern is particularly relevant for understanding the mechanisms through which prolonged repetition of rotational movements under load may contribute to the progressive wear of the articular cartilage. In Figure 3, the loads and actions that develop during the turning moments of the hammer throw technique and their impact on the thrower's anatomical structure are represented.

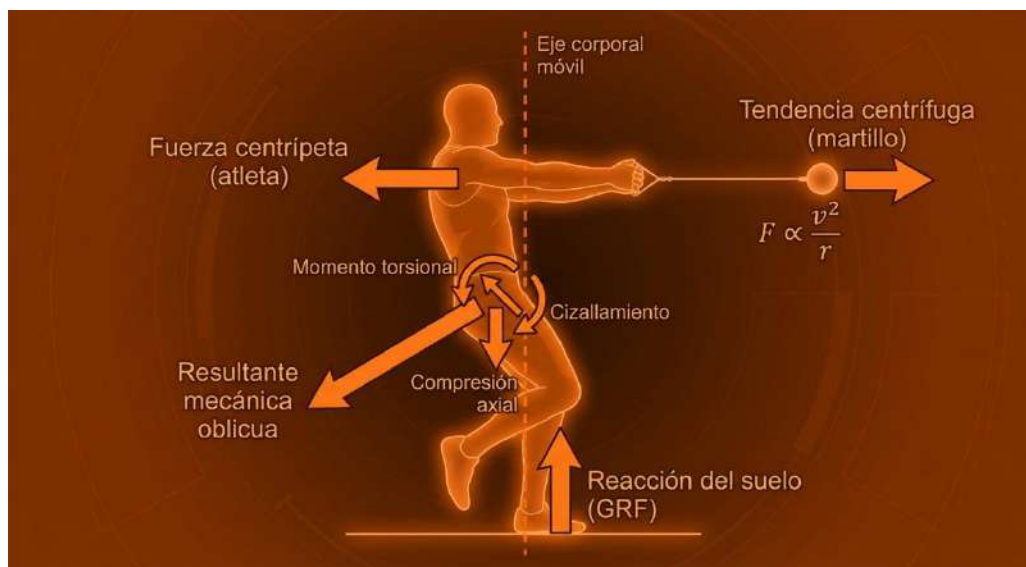


Figure 3: Biomechanical model of the hammer throw

Source: Author's own elaboration, supported by artificial intelligence, based on the description of human movement in the hammer throw.

The integration of the observed biomechanical elements allows the hammer throw technique to be interpreted as an amplified model of rotational load transfer acting on the coxofemoral joint. The interaction between angular acceleration, ground reaction force, and postural control generates a system of forces that converges at the hip as the central articulation point between the trunk and the lower limbs. In this context, the hip not only supports vertical load but also acts as an axis for the transmission of rotational moments and shear forces; see Figure 4. This biomechanical configuration allows a deeper understanding of how human tasks that combine lifting and repetitive rotation can generate mechanical conditions favorable to the long-term development of joint wear.



Figure 4: Loads and force moments in the hammer throw technique
 Source: Author's own elaboration with the support of artificial intelligence, based on the description of human movement in the hammer throw.

5. DISCUSSION

The results obtained allow the technical gesture of the hammer throw to be understood as a highly informative biomechanical model for the analysis of rotational loads acting on the coxofemoral joint. Unlike traditional models of occupational ergonomics that focus primarily on the weight handled or on the frequency of lifting tasks, the analysis developed in this study highlights the relevance of the kinematic configuration of the movement. The interaction between trunk rotation, body inclination, and dynamic weight transfer generates a three-dimensional distribution of forces in the hip joint that cannot be explained solely by the magnitude of the external load. This finding is consistent with recent research indicating that the risk of occupational osteoarthritis increases when work tasks involve trunk rotation under load, particularly in contexts where manual material handling occurs in confined spaces or under constrained postures (Jahn et al., 2024).

From a biomechanical perspective, the rotational analysis demonstrates that the centripetal force generated by the movement of the implement produces increasing tension within the athlete–hammer system as the angular velocity of the gesture increases. This tension must be compensated through a continuous reorganization of body posture, in which the lower limbs play a fundamental role in the generation

of angular momentum and in maintaining dynamic balance. The ground reaction force, transmitted through the lower limbs, acts as a mechanism for transferring mechanical energy to the rotational system. In this process, the coxofemoral joint becomes the central point of convergence of forces originating from both the trunk and the lower extremities. The convergence of these forces generates an oblique mechanical resultant that is transmitted toward the hip through three main components: axial compression, shear forces, and torsional moments. This pattern is consistent with biomechanical models previously described in studies of joint loading, where it has been demonstrated that the combination of compressive and shear forces significantly increases stress on the acetabular cartilage (Amiri et al., 2022). This biomechanical pattern suggests that ergonomic models based exclusively on the magnitude of vertical load may underestimate joint risk in tasks that incorporate trunk rotation under load, and therefore should be analyzed as structures responding to complex interactions of three-dimensional forces during dynamic movements. The ergonomic interpretation of these results becomes particularly relevant when the biomechanical configurations of the hammer throw are compared with work tasks that involve trunk rotation under load. In manual material handling operations, particularly during the unloading of cement bags or the manipulation of heavy tools in industrial environments, workers frequently perform movements that combine hip flexion, axial rotation, and lateral weight transfer. Although the rotational velocities in these contexts are considerably lower than those observed in the analyzed sports gesture, the prolonged repetition of these sequences may lead to the accumulation of microtrauma in the joint structures.

The theory of cumulative mechanical damage proposes that the progressive deterioration of articular cartilage does not necessarily require high peak loads, but may arise from the constant repetition of moderate loading cycles that exceed the tissue's capacity for recovery (Harris & Coggon, 2015). From this perspective, the hammer throw gesture functions as an amplified representation of a biomechanical pattern that may also be observed in intensive physical work. The fundamental difference lies in the temporal scale: while the sports gesture concentrates large magnitudes of force within brief intervals, occupational tasks may reproduce similar mechanical configurations over thousands of cycles during a working day.

Another relevant element identified in this study is the role of body inclination in the redistribution of forces within the rotational system. During the advanced phases of the throw, the athlete adopts a posterior trunk inclination that allows the centrifugal force generated by the hammer to be balanced. This postural strategy modifies the orientation of the mechanical resultant transmitted toward the hip, altering the distribution of loads within the joint. In ergonomic terms, this phenomenon is particularly interesting because it suggests that small changes in posture may significantly modify the direction and magnitude of the forces acting on the hip.

The literature on gait biomechanics and rotational movements has also demonstrated that contact forces at the hip joint may reach values of five to seven times body weight during dynamic activities involving trunk rotation (Harada et al., 2023). These findings support the idea that effective joint loading depends more on the interaction between muscular forces and movement configuration than on the

observable external load. Consequently, the ergonomic assessment of joint degeneration risk should incorporate more detailed analyses of movement kinematics rather than relying solely on estimates based on handled weight.

From a methodological perspective, the use of the hammer throw as a generating biomechanical model presents important analytical advantages. As it is a highly structured movement that has been widely studied in sports biomechanics, it allows the sequence of mechanical events leading to the generation of high rotational forces to be clearly identified. This structural clarity facilitates the interpretation of the mechanisms of load transfer toward the coxofemoral joint. However, it is also necessary to recognize that the sports context presents conditions of technical control that are not always present in everyday physical work.

For or this reason, the analytical transfer between the sports gesture and occupational tasks should be interpreted as a conceptual tool rather than as a direct equivalence of mechanical loads. The objective is not to assert that the magnitudes of force present in the hammer throw are reproduced in work activities, but rather to use the biomechanical structure of the gesture to understand how certain movement configurations may amplify joint loading. This approach expands the interpretative framework of occupational ergonomics and introduces kinematic variables that have traditionally received less attention in the assessment of musculoskeletal risk.

Taken together, the results obtained suggest that joint degeneration associated with physically demanding work cannot be understood solely on the basis of the magnitude of handled loads. Movement configuration, the temporal sequence of efforts, and the interaction between rotation and muscular stabilization constitute key variables in the generation of internal loading on the coxofemoral joint. Integrating these elements into ergonomic analysis allows progress toward more comprehensive risk-assessment models capable of capturing the three-dimensional complexity of human work.

6. CONCLUSIONS

The present study made it possible to analyze hip joint degeneration from an expanded biomechanical perspective, incorporating the analysis of rotational configurations of human movement as a relevant factor in the generation of joint loading. A review of the scientific literature identified that traditional models of ergonomic assessment have primarily emphasized the magnitude of handled weight, the frequency of lifting tasks, and the duration of exposure. However, recent evidence indicates that these approaches may be insufficient to explain the development of hip osteoarthritis in activities where load handling is combined with trunk rotation, sustained hip flexion, and dynamic reorganization of the base of support. In this context, biomechanical analysis of movement becomes a fundamental element for understanding the three-dimensional distribution of forces acting on the coxofemoral joint.

The biomechanical characterization of the hammer throw technique made it possible to identify a complex rotational system in which the interaction between angular velocity, effective radius of the implement, and ground reaction force

generates a dynamic structure of loads that converges at the hip joint. This system simultaneously produces components of axial compression, shear forces, and torsional moments that must be compensated through the coordinated activation of the stabilizing muscles of the trunk and lower limbs. The kinematic analysis of the gesture showed that the progressive acceleration of the implement depends mainly on the transfer of mechanical energy from the body system to the rotational movement, which makes the hip a key point for the transmission of forces between the trunk and the lower extremities.

The ergonomic reinterpretation of this sports gesture made it possible to identify biomechanical patterns comparable to those found in occupational tasks involving manual material handling under conditions of trunk rotation. Activities such as the manual unloading of cement bags, the manipulation of heavy tools, or the lateral transfer of loads in confined spaces present movement configurations that combine hip flexion, axial torsion, and dynamic body stabilization. Although the magnitudes of angular velocity present in work activities are considerably lower than those in the hammer throw, the prolonged repetition of these mechanical configurations may generate the accumulation of microtrauma in joint structures, promoting long-term degenerative processes.

From an ergonomic perspective, the results obtained suggest that the assessment of joint degeneration risk should incorporate analysis of the kinematic structure of movement and should not be limited exclusively to estimates based on handled weight. The interaction between trunk rotation, body inclination, and dynamic load transfer modifies the orientation of the forces transmitted toward the coxofemoral joint, generating oblique loading patterns that may increase stress on the acetabular cartilage. Integrating these variables into ergonomic analysis allows the development of more comprehensive evaluation models capable of capturing the three-dimensional complexity of human tasks and improving the identification of risk factors associated with the development of musculoskeletal disorders.

Finally, the study provides a methodological approach based on the use of generating biomechanical models derived from the analysis of highly complex human movements. The hammer throw, interpreted from this perspective, allows the dynamic structure of rotational loading acting on the musculoskeletal system to be observed in an amplified manner. This approach contributes to expanding the analytical framework of occupational ergonomics by providing conceptual tools that facilitate understanding of how specific movement configurations may influence the generation of joint loading. Consequently, the integration of detailed biomechanical analyses into the evaluation of physical work may represent an important advance in the design of preventive strategies aimed at preserving the joint health of workers exposed to tasks of high physical demand.

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ERGONOMIC ASSESSMENT OF THE PACKAGING AND ARRANGEMENT PROCESS OF PURIFIED WATER BOTTLES IN ACCORDANCE WITH NOM-036-1-STPS-2018 TO DETERMINE ERGONOMIC RISKS.

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Resumen: La presente investigación analiza los factores de riesgo ergonómico derivados del Manejo Manual de Cargas (MMC) en una planta purificadora de agua en Los Mochis, Sinaloa. El estudio se centra en el puesto de empaquetado y acomodo de paquetes de 16 botellas de 1 litro, utilizando la metodología de estimación simple de riesgo establecida en el Apéndice I de la NOM-036-1-STPS-2018. Los resultados identificaron un nivel de riesgo alto en la actividad de empaquetado y muy alto e inaceptable en el transporte manual y acomodo. Se concluye que existe una justificación técnica para la implementación inmediata de medidas de control administrativas y de ingeniería para prevenir trastornos musculoesqueléticos (TME) y fatiga física en los operarios.

Palabras clave: Salud ocupacional, Cargas manuales, Lumbalgias, Higiene postural

Relevancia para la ergonomía: Este estudio aporta evidencia aplicada sobre el uso del Apéndice 1 de la NOM-036-1-STPS-2018 como herramienta de estimación ergonómica en entornos industriales de embotelladoras de agua. Asimismo, demuestra la utilidad de los métodos de estimación cualitativa para la detección temprana de riesgos ergonómicos, facilitando la toma de decisiones preventivas sin requerir instrumentación compleja. Los resultados contribuyen al fortalecimiento de la ergonomía ocupacional al vincular el cumplimiento normativo con la prevención efectiva de trastornos musculoesqueléticos.

Abstract: This research analyzes the ergonomic risk factors associated with Manual Handling of Loads (MHL) at a water purification plant in Los Mochis, Sinaloa. The study focuses on the packaging and stacking of 16-bottle packs of 1 liter bottles, using the simple risk estimation methodology established in Appendix I of NOM-036-1-STPS-2018. The results identified a high risk level in the packaging activity and a very high and unacceptable risk level in manual handling and stacking. It is

concluded that there is a technical justification for the immediate implementation of administrative and engineering control measures to prevent musculoskeletal disorders (MSDs) and physical fatigue in the operators.

Keywords: Occupational Health, Manual Loading, Lower Back Pain, Postural Hygiene.

Relevance to ergonomics: This study provides applied evidence on the use of Appendix 1 of NOM-036-1-STPS-2018 as an ergonomic assessment tool in industrial environments of water bottling plants. It also demonstrates the usefulness of qualitative assessment methods for the early detection of ergonomic risks, facilitating preventive decision-making without requiring complex instrumentation. The results contribute to strengthening occupational ergonomics by linking regulatory compliance with the effective prevention of musculoskeletal disorders.

1. INTRODUCTION

Manual handling of loads (MHL) is one of the most frequent work activities in manufacturing and product processing workplaces, such as water purification plants. At first glance, the task of transporting packs of 16 one-liter bottles may seem routine; however, it involves repetitive and biomechanically demanding physical efforts that represent a significant ergonomic risk to the musculoskeletal health of workers.

According to Appendix 1 of NOM-036-1-STPS-2018, the analysis of ergonomic risk factors arising from manual handling of loads must include the identification of activities, a simple estimation of the risk level, and, when necessary, a specific risk assessment STPS 2018 (Secretariat of Labor and Social Welfare, 2018).

According to Ruiz et al. (2022), in their article "Identification of the Ergonomic Risk Level Due to Load Handling and Repetitive Movements in the Food Industry," the risk from load handling and repetitive movements is present in 87.3% of jobs. Therefore, we undertook an estimation of the risk associated with manual load handling for operators in a water purification plant.

2. OBJECTIVES

General objective: To estimate the impact of ergonomic risk in the manual handling of loads at the packaging workstation in a water purification plant, by applying NOM-036-1-STPS-2018, in order to identify critical activities that pose a risk to musculoskeletal health.

Specific Objectives:

- Identify the manual handling activities during the packaging and stacking of 16-bottle packs of 1 liter bottles, in order to recognize the most physically demanding activities.

- Estimate the level of ergonomic risk associated with the weight, frequency of handling, and postures adopted by the operator, in accordance with NOM-036-1-STPS-2018, to determine the magnitude of the risk present in the workplace.
- Propose improvement actions aimed at reducing ergonomic risk, to contribute to the prevention of musculoskeletal injuries in operators.

3. METHODOLOGY

3.1 Visit to the Purification Plant

The process under analysis is the packaging of 1000 ml and 1500 ml bottles, which is done manually in shifts of 4 to 8 hours. During these shifts, the operators package continuously with short breaks.

The task requires constant effort, as the packages weigh between 16 and 24 kg, and the facilities are not optimal.

3.2 Risk Mapping

An ergonomic risk mapping was conducted in the area where 1-liter bottles are packaged and arranged in bundles of 16 bottles each, using the Corlett and Bishop method. This method allowed for the identification of body areas with the greatest discomfort resulting from task performance. The information was obtained from observing the operator's activities and identifying the body regions with the most discomfort, which were then represented in a body diagram to facilitate visualization of the areas with the greatest physical strain during the workday.

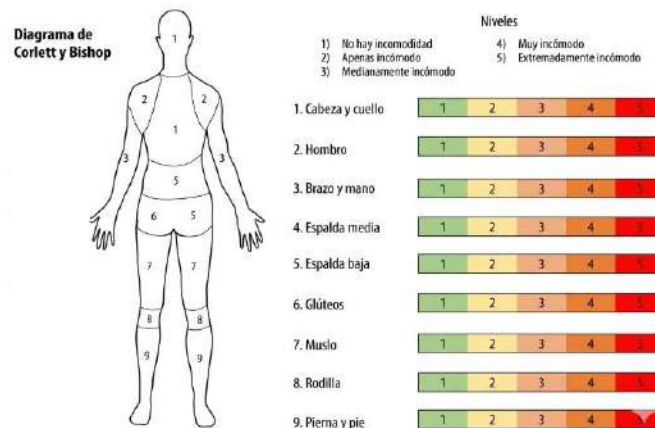


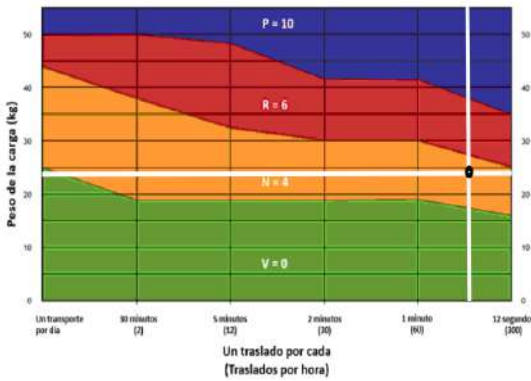
Figure 1. Corlett and Bishop Diagram.

3.3 Ergonomic Risk Assessment in the Packaging Area

The ergonomic risk level was assessed for the packaging, transport, and storage of 1-liter bottle bundles, each containing 16 bottles, using the simple assessment procedure established in Appendix I of NOM-036-1-STPS-2018.

Factors such as load weight, handling frequency, worker postures, grip conditions, work surface, and environmental conditions of the area were analyzed. Each factor was assigned a score according to the standard's criteria, allowing for the determination of the ergonomic risk level present in each evaluated activity.

Table 1. Risk assessment procedure in the survey.

Risk factor	Estimation reference.
a) Load weight and frequency: Record the weight and frequency of the transport operation. Results: For this step, we used the 1500 ml package, which has an 85-second packaging cycle, during which three lifts are performed. This averages out to a lift of 24 kg every 28 seconds; therefore, it is assigned a value of 4 points.	Peso de la carga/frecuencia, gráfica para operaciones de transporte 
b) Horizontal distance between hands and lower back: Observe the task and examine the horizontal distance between the worker's hands and lower back, always considering the "worst-case scenario." Results: As seen in the image, when handling the package, the arms are not fully aligned with the torso. Therefore, it is considered a regular grip and is given a score of 3 points.	 

c) Vertical lifting region: Observe the worker's hand position at the start of the lift and as the operation progresses. Always evaluate the "worst-case scenario".

Results: This operation is assigned a value of **3 points**, which indicates that, although the lift does not reach head height, the torso is subjected to a tilt, making the operation high-risk.

Por encima de la rodilla y/o por debajo de la altura del codo Nivel: Verde Valor:0	Por debajo de la rodilla y/o por encima de la altura del codo Nivel: Naranja Valor:1	A la altura de la cabeza o por arriba, o a nivel de piso o por debajo Nivel: Rojo Valor:3



d) Torso twisting and lateral flexion:

I. Observe the worker's torso as they lift the load. If the torso twists relative to the hips and thighs, or if the worker leans to one side while lifting the load, the band color is orange.

II. If the torso twists and bends to one side while lifting the load, the band color is red.

Results: In this operation, it is necessary to rotate the package 90 degrees to cover the missing side, which results in a torso rotation close to 90 degrees. Therefore, it is given a value of **2 points**.

Poca o ninguna torsión o flexión lateral del torso. Nivel: Verde Valor:0	Torsión o flexión lateral del torso Nivel: Naranja Valor:1	Torsión y flexión lateral del torso Nivel: Rojo Valor:2





e) Postural Restrictions:

I. If the worker's movements are not obstructed, the band will be green;

II. If the worker adopts awkward or forced postures while lifting a load due to available space (e.g., limited space between team members) or the workstation design (e.g., an excessively high monorail conveyor), the band will be orange; and

III. If the posture is severely restricted, the band will be red and the numerical score will be 3 (e.g., work in confined areas such as a warehouse).

Results: When positioning the package on the left side to detach a sheet of stretch film, a forced posture was adopted, therefore a value of 1 point was assigned.

Sin restricciones posturales	Postura restringida	Postura severamente restringida
Nivel: Verde	Nivel: Naranja	Nivel: Rojo
Valor: 0	Valor: 1	Valor: 3



f) Hand-load coupling (gripping elements): This factor considers the geometric and design properties of the load to be handled, in terms of its interaction with the worker's hands.

Results: Regarding gripping conditions, the hold is classified as fair. This is because, although the surface of the bottle package is flat, it lacks handles or grips, resulting in a score of **1 point**.

Buen agarre	Agarre regular	Mal agarre
Contenedores con elementos de sujeción, como asas o manijas bien diseñados, aptos para este propósito.	Contenedores con asas o manijas mal diseñadas; El material permite hacer un agarre con la mano en pinza;	Contenedores de diseño pobre. Partes holgadas, objetos irregulares, voluminosos o difíciles de manejar
Partes holgadas que permiten un agarre cómodo.	Los dedos deben estar sujetos a 90 grados bajo el contenedor o la carga.	Sacos no rígidos (como bultos de arena o cemento) cargas impredecibles
Nivel: Verde Valor:0	Nivel: Naranja Valor:1	Nivel: Rojo Valor:2



g) Work surface: This factor considers the properties of the surface where the worker walks or stands.

Results: The packaging station is adjacent to the bottle washing area, resulting in constant moisture on the floor. Therefore, it is assigned a value of **2 points**.

Piso seco, limpio y en buenas condiciones de mantenimiento	Piso seco, pero en malas condiciones, desgastado o irregular	Piso contaminado/húmedo o desnivelado, superficie inestable o calzado inadecuado
Nivel: Verde Valor:0	Nivel: Naranja Valor:1	Nivel: Rojo Valor:2

h) Other environmental factors:

I. Observe the work environment and determine if the lifting operation is carried out under: extreme temperatures; with strong air circulation; or in extreme lighting conditions (too dark or too bright). If one of these risk factors is present, the band color will be orange;

II. If two or more risk factors are present, the band color will be red; and

III. If no risk factor exists, the band color will be green.

Results: Bottle packaging is carried out in an area with very high temperatures, high humidity, and poor lighting; therefore, it is assigned a value of **2 points**.

Sin factores de riesgo presentes	Un factor de riesgo presente	Dos o más factores de riesgo presentes
Nivel: Verde Valor:0	Nivel: Naranja Valor:1	Nivel: Rojo Valor:2

I) Transport distance: Observe the activity and estimate the total distance that the load (total path) is transported, in meters.	N/A
i) Obstacles on the route: I. Observe the route. If the worker has to carry a load and there is only one risk factor present, such as: a steep slope (with an incline greater than 20%), climbing stairs, passing through closed doors, or around materials that could cause tripping, the band color will be orange; II. If the task involves carrying the load up stairs, the band color will be red; III. If the task involves more than one of the risk factors (for example, a slope with an incline greater than 20% followed by climbing stairs), the band color will be red; and IV. If there are no risk factors, the band color will be green.	N/A

Table 2. Risk assessment procedure in transport and accommodation.

Risk factor	Reference estimate.
a) Load weight and frequency: Record the weight and frequency of the transport operation. Result: For this risk factor, we considered the 1500 ml package, which is transported to the finished product warehouse every 85 seconds. Given the high frequency of repetition and the size of the load, a weighting of 4 points was assigned.	Peso de la carga/frecuencia, gráfica para operaciones de transporte

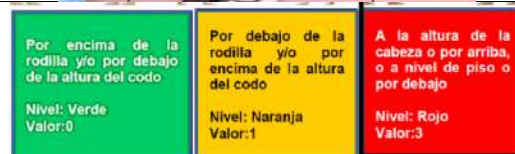
b) Horizontal distance between hands and lower back: Observe the task and examine the horizontal distance between the worker's hands and lower back, always considering the "worst-case scenario."

Result: It was identified that, during final stacking, the worker flexes their torso at an angle greater than 60°. Due to this postural issue, a score of **6 points is assigned**.



c) Vertical Lifting Region: Observe the worker's hand position at the start of the lift and as the operation progresses. Always evaluate the "worst-case scenario".

Results: This operation is assigned a value of **3 points**, which indicates that, although the lift does not reach head height, the torso is subjected to a tilt, making the operation high-risk.



d) Torso twisting and lateral flexion:

I. Observe the worker's torso as they lift the load. If the torso twists relative to the hips and thighs, or if the worker leans to one side while lifting the load, the band color is orange.

II. If the torso twists and bends to one side while lifting the load, the band color is red.

Results: It was observed that, during unloading at hard-to-reach points, the worker combines lateral flexion to compensate for the distance with axial rotation of the trunk when positioning the package. This combination of asymmetrical movements places the task at a high risk level with a score of **2 points**.

Poca o ninguna torsión o flexión lateral del torso. Nivel: Verde Valor:0	Torsión o flexión lateral del torso Nivel: Naranja Valor:1	Torsión y flexión lateral del torso Nivel: Rojo Valor:2

**e) Postural Restrictions:**

I. If the worker's movements are not obstructed, the band will be green;

II. If the worker adopts awkward or forced postures while lifting a load due to available space (e.g., limited space between team members) or the workstation design (e.g., an excessively high monorail conveyor), the band will be orange; and

III. If the posture is severely restricted, the band will be red and the numerical **score will be 3** (e.g., working in confined areas such as a warehouse).

Results: When positioning the package in the finished product area, the operator adopts a forced posture and also has an obstruction in front, therefore a score of **1 point is assigned**.

Sin restricciones posturales Nivel: Verde Valor:0	Postura restringida Nivel: Naranja Valor:1	Postura severamente restringida Nivel: Rojo Valor:3



f) Hand-load coupling (gripping elements): This factor considers the geometric and design properties of the load to be handled, specifically its interaction with the worker's hands.

Results: When carrying the packages, they are gripped with the fingers by the underside, creating a 90-degree angle. This results in a weighting of **1 point**.

Bien agarre	Agarre regular	Mal agarre
Contenedores con elementos de sujeción, como asas o manijas bien diseñados, aptos para este propósito.	Contenedores con asas o manijas mal diseñadas; El material permite hacer un agarre con la mano en pinza;	Contenedores de diseño pobre. Partes holgadas, objetos irregulares, voluminosos o difíciles de manejar
Partes holgadas que permiten un agarre cómodo.	Los dedos deben estar sujetos a 90 grados bajo el contenedor o la carga.	Sacos no rígidos (como bultos de arena o cemento) cargas impredecibles
Nivel: Verde Valor:0	Nivel: Naranja Valor:1	Nivel: Rojo Valor:2



g) Work surface: This factor considers the properties of the surface where the worker walks or stands.

Results: The plant floor is constantly damp and has considerable unevenness. Furthermore, the operators do not wear non-slip footwear. Therefore, the work surface is considered a high-risk factor with a score of **3 points**.

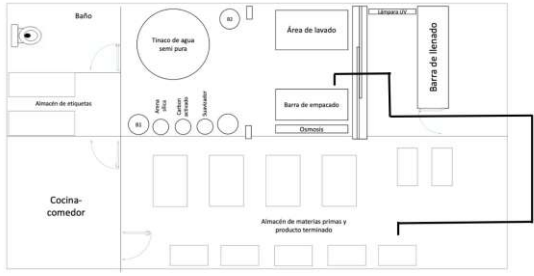
Piso seco, limpio y en buenas condiciones de mantenimiento	Piso seco, pero en malas condiciones, desgastado o irregular	Piso contaminado/húmedo o desnivelado, superficie inestable o calzado inadecuado
Nivel: Verde Valor:0	Nivel: Naranja Valor:1	Nivel: Rojo Valor:2

h) Other environmental factors:

I. Observe the work environment and determine if the lifting operation is carried out under: extreme temperatures; with strong air circulation; or in extreme lighting conditions (too dark or too bright). If one of these risk factors is present, the band color will be orange;

II. If two or more risk factors are present, the band color will be red; and

Sin factores de riesgo presentes	Un factor de riesgo presente	Dos o más factores de riesgo presentes
Nivel: Verde Valor:0	Nivel: Naranja Valor:1	Nivel: Rojo Valor:2

III. If no risk factor exists, the band color will be green. Results: Bottle packaging is carried out in an area with very high temperatures, high humidity, and poor lighting; therefore, it is assigned a value of 2 points.	
i)Transport distance: Observe the activity and estimate the total distance that the load (total path) is transported, in meters.	2 a 4 m Nivel: Verde Valor:0 Más de 4 m y menos de 10 m Nivel: Naranja Valor:1 Más de 10 m Nivel: Rojo Valor:3  The floor plan diagram shows a facility with several rooms and areas. A path is highlighted with a thick black line, starting from the 'Almacén de materias primas y producto terminado' (Raw material and finished product warehouse) area, moving through the 'Cocina-comedor' (Kitchen-dining area), and ending at the 'Barra de lavado' (Washing bar). Other labeled areas include 'Baño' (Bathroom), 'Almacén de etiquetas' (Label warehouse), 'Tanco de agua semi pura' (Semi-pure water tank), 'Área de lavado' (Washing area), 'Barra de empaque' (Packaging bar), 'Olimpico', and 'Barra de llenado' (Filling bar).

j) Obstacles on the route:

I. Observe the route. If the worker has to carry a load and there is only one risk factor present, such as: a steep slope (with an incline greater than 20%), climbing stairs, passing through closed doors, or around materials that could cause tripping, the band color is orange.

II. If the task involves carrying the load up stairs, the band color will be red.

III. If the task involves more than one of the risk factors (for example, a slope with an incline greater than 20% followed by climbing stairs), the band color will be red.

IV. If there are no risk factors, the band color will be green.

Results: The route used to transport the packages to the finished product warehouse has considerable changes in level, such as steps and a ramp. Additionally, the worker passes through a narrow doorway. This combination of factors results in a high risk factor, rated at **3 points**.

Sin obstáculos y la ruta de transporte es plana Nivel: Verde Valor:0	Pendiente pronunciada o subir escalones o pasar a través de puertas estrechas o riesgo de tropezar Nivel: Naranja Valor:1	Subir por escaleras y/o pendientes empinadas Nivel: Rojo Valor:3



Table 3. Risk level estimate.

Risk factors	Get up		Transport		Equipment	
	Color	Valor	Color	Valor	Color	Valor
Weight and load elevation/frequency of transport		4		4		NA

Horizontal distance between the hands from the lower back		3		6		NA
Vertical lift region		3		3		NA
Torsion and lateral flexion of the torso; Asymmetrical load on the torso (transport)		2		2		NA
Postural restrictions (uncomfortable, forced, or restricted postures)		1		1		NA
Hand-load coupling (fastening elements)		1		1		NA
Work surface		2		2		NA
Other environmental factors		2		2		NA
Transport distance		NA		1		NA
Obstacles on the route (transport only)		NA		1		NA
Communication, coordination and control (manual handling of loads in equipment only)		NA		NA		NA
Punctuation	18		23			
Risk Level						

3.4 Improvement Proposals Based on the Results Obtained from NOM-036-1-STPS-2018

Based on the results obtained from the ergonomic risk assessment according to Appendix 1 of NOM-036-1-STPS-2018, improvement proposals were developed to reduce physical exertion and awkward postures during the packaging, transport,

and arrangement of bottle bundles. These proposals focus on improving workplace conditions and reducing manual handling of loads.

4. RESULTS

4.1 Risk Mapping

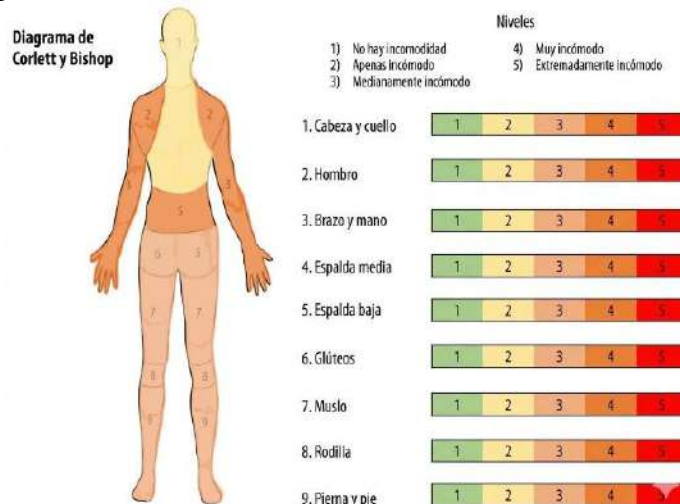


Figure 2. Corlett and Bishop Diagram.

The Corlett and Bishop diagram shows that the head and neck present a level 2 (slightly uncomfortable), while the shoulders register a level 3 (moderately uncomfortable). The greatest discomfort is identified in the arms and hands, as well as in the mid and lower back, with a level 4 (very uncomfortable). Meanwhile, the lower extremities (buttocks, thighs, knees, legs, and feet) primarily show a level 3 (moderately uncomfortable).

4.2 Estimation of the Ergonomic Risk Level in the Packaging Area

According to the estimation performed in accordance with NOM-036-1-STPS-2018, Appendix 1, a score of 18 was obtained for the lifting activity and 23 for the carrying activity. These values indicate that the carrying stage represents a higher level of risk for the worker, since it involves maintaining the load during movement, which increases the physical demands.

The factors that most influence the level of risk are the weight of the load, the horizontal distance between the load and the body, and the frequency of handling—elements that increase the biomechanical load on the back, arms, and shoulders. Taken together, these results show that the worker is exposed to an ergonomic risk that can contribute to physical fatigue and potential musculoskeletal disorders if the activity is performed repetitively or for prolonged periods.

4.3 Improvement Proposals Based on the Results Obtained from NOM-036-1-STPS-2018

Engineering Redesign and Workstations:

- Height Adjustment (Anthropometry): Modify the packaging tables so that the handling area is at the operator's elbow height (avoiding trunk flexions greater than 20°).
- Implementation of Conveyors: Eliminate manual transport between the packaging area and the palletizing area by using pallet jacks, reducing carrying effort.
- Mechanical Lifting Aids: Install scissor lift tables for palletizing so that the worker always places the package at the same height, eliminating the need to bend down to ground level.

Organizational measures:

Active breaks and compensatory stretching program: Implement 5-minute micro-breaks every hour, specifically designed to lengthen the paravertebral muscles and arm flexors.

Biomechanical technique training: Instruct not only on "bending the knees," but also on managing the center of gravity of the load and the importance of avoiding twisting movements (pivoting on the feet instead of twisting at the waist).

5. CONCLUSION

The assessment using NOM-036-1-STPS-2018 is relevant and essential for the manual handling of loads in water purification plants, as it establishes a technical framework for identifying and evaluating ergonomic risk factors. The application of Appendix I (Simple Risk Assessment) allowed for the analysis of key variables such as lifting frequency, transport distances, and postures adopted during the evaluated activities.

The results show a high risk level in the packaging activity and a very high risk level in the transport and placement of packages, demonstrating significant exposure to physical exertion that can lead to musculoskeletal disorders, primarily in the lumbar region and shoulders. These findings allow for the identification of critical areas in the process and highlight the need to implement improvement measures that contribute to reducing ergonomic risk and improving working conditions for personnel.

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ERGONOMIC ENGINEERING INTERVENTION FOR DRYWALL (TABLAROCA) SHEET HANDLING: DESIGN AND EVALUATION OF AN AUXILIARY TRANSPORT DEVICE IN A RETAIL HARDWARE STORE

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Resumen: La manipulación manual de materiales (MMM) continúa siendo una de las principales fuentes de exposición a trastornos musculoesqueléticos relacionados con el trabajo (TME) en actividades de comercio y suministro, particularmente en pequeñas y medianas empresas donde el uso de ayudas mecánicas suele ser limitado. En este contexto, el manejo de hojas de tablaroca representa una tarea de alto riesgo debido a sus dimensiones, peso, dificultad de agarre, obstrucción del campo visual y exigencias posturales asociadas al levantamiento, traslado y posicionamiento. El presente estudio documenta una intervención de ingeniería ergonómica aplicada en una ferretería de Cd. Cuauhtémoc, Chihuahua, México, orientada al rediseño de esta tarea mediante el desarrollo de un dispositivo auxiliar de transporte de bajo costo, con base en principios de ergonomía ocupacional y normalización internacional para manejo manual de cargas.

La metodología consistió en una evaluación de campo de corte transversal con observación directa, registro fotográfico y análisis ergonómico pre y post intervención. En la fase diagnóstica se aplicaron herramientas estandarizadas de evaluación rápida: REBA (Rapid Entire Body Assessment) para caracterizar la carga postural global durante las fases de levantamiento, transporte y reposicionamiento, y el método MAC Tool (Manual Handling Assessment Charts) de HSE para estimar la exposición asociada a operaciones de levantamiento y transporte. Los hallazgos iniciales evidenciaron una condición crítica de riesgo: puntuación REBA de 13 (riesgo muy alto; acción inmediata) y puntuación MAC de 20 (categoría de acción 3), lo que justificó el diseño e implementación de un control de ingeniería enfocado en sustituir el acarreo manual por transporte asistido.

A partir de los resultados del diagnóstico se definieron requerimientos explícitos de diseño ergonómico: altura de agarre ubicada entre cadera y codo para

favorecer la capacidad de empuje y reducir la carga en hombros y zona lumbar; reducción de resistencia al rodamiento mediante ruedas adecuadas y rodamientos; y sistema de estabilización de la carga para mejorar el control del centro de masa y disminuir agarres asimétricos y flexión de tronco. Tras la fabricación e implementación del prototipo, la evaluación post intervención mostró reducción de la exposición en MAC a 12 (levantamiento) y 9 (transporte), ambos dentro de la categoría de acción 2, equivalentes a una disminución relativa de 40% a 55% respecto a la línea base. De manera cualitativa, se observaron mejoras en estabilidad, reducción de flexión del tronco y menor demanda de agarres comprometidos.

El trabajo aporta un caso aplicado y replicable para PYMES, al integrar un flujo completo de intervención ergonómica: identificación del riesgo, traducción a criterios de diseño y verificación del efecto mediante evaluación posterior. Además, evidencia cómo los principios de la normalización internacional en manipulación manual pueden operacionalizarse mediante soluciones de ingeniería pragmáticas, fortaleciendo la toma de decisiones basada en evidencia para el diseño de sistemas de trabajo más seguros y factibles en contextos reales de recursos limitados

Palabras clave: Evaluación ergonómica, Riesgo musculoesquelético, MAC Tool, Instrumento de transporte auxiliar.

Relevancia para la ergonomía: Este estudio de caso contribuya a la ergonomía ocupacional y a la evaluación del trabajo documentando un flujo de trabajo aplicado de trabajo aplicado de extremo a extremo: (1) identificación de riesgos a nivel de tarea utilizando herramientas ergonómicas de evaluación estandarizadas (REBA, MAC Tool); (2) traducción de resultados en requisitos explícitos de diseño; y (3) verificación de la reducción de exposición mediante puntuación posterior a la intervención. Como ejemplo replicable para las PYMES, ilustra como los conceptos internacionales de normalización para la manipulación manual pueden operacionalizarse mediante el diseño de ingeniería y la evaluación rápida, apoyando decisiones basadas en la evidencia para sistemas de trabajo más seguros.

Abstract: Manual material handling (MMH) remains a major source of exposure to work-related musculoskeletal disorders (WMSDs), especially in small and medium-sized enterprises where mechanical aids are often scarce or absent. In retail hardware environments, drywall sheet handling is a particularly high-risk task because of the load's dimensions, weight distribution, poor grasp conditions, visual obstruction, and the postural demands associated with lifting, carrying, and positioning. This chapter presents an applied ergonomic engineering intervention conducted in a retail hardware store in Cuauhtémoc, Chihuahua, Mexico, aimed at redesigning this task through the development and evaluation of a low-cost auxiliary transport device, grounded in occupational ergonomics principles and international manual-handling standardization concepts.

The study followed a cross-sectional field evaluation approach with direct observation, photographic documentation, and pre/post ergonomic assessment. Baseline risk characterization employed standardized rapid assessment tools:

REBA (Rapid Entire Body Assessment) to evaluate whole-body postural load during lifting, carrying, and repositioning activities, and the HSE Manual Handling Assessment Charts (MAC Tool) to estimate exposure during lifting and carrying operations. Initial findings showed a critical risk condition: a REBA score of 13 (very high risk, immediate action required) and an MAC score of 20 (Action Category 3), supporting the need for a prompt engineering control strategy focused on replacing manual carrying with assisted transport

Design requirements were explicitly derived from the ergonomic assessment outcomes and manual-handling guidance: handle height positioned between hip and elbow to improve push capability and reduce shoulder and low-back loading; low rolling resistance through appropriate wheel diameter and bearings; and load stabilization features to improve center-of-mass control while reducing awkward gripping and trunk asymmetry. After prototype fabrication and implementation, post-intervention MAC assessment showed reduced exposure scores of 12 (lifting) and 9 (carrying), both within Action Category 2, representing an estimated 40% to 55% reduction relative to the baseline condition. Qualitative observations further indicated improved load stability, less trunk flexion, and fewer asymmetric handling postures during task execution.

This work contributes a practical and replicable example for SMEs by documenting a complete ergonomic intervention workflow: task-level risk identification, translation of findings into engineering design criteria, and verification of risk reduction through post-intervention scoring. The case also illustrates how international standardization concepts for manual handling can be operationalized through feasible engineering solutions in resource-constrained environments. Beyond its local impact, the intervention supports evidence-based decision-making for safer work systems and highlights the value of combining rapid ergonomic assessment tools with low-cost design innovation in occupational settings where bulky materials are routinely handled

Keywords: Ergonomic Assessment, WMSD risk, drywall sheets handling, MAC Tool, Auxiliary Transport device.

Relevance to ergonomics: This case study contributes to occupational ergonomics and work evaluation by documenting an end-to-end applied workflow: (1) task-level risk identification using standardized assessment tools (REBA, MAC tool); (2) translation of results into explicit design requirements; and (3) verification of exposure reduction with post-intervention scoring. As a replicable example for SMEs, it illustrates how international standardization concepts for manual handling can be operationalized through engineering design and rapid evaluation, supporting evidence-based decisions for safer work systems.

1. INTRODUCTION

Manual material handling (MMH) is a well-recognized contributor to work-related musculoskeletal disorders (WMSDs), especially in small and medium enterprises

where bulky materials are frequently moved with limited mechanical assistance. In retail/hardware settings, drywall (tablaroca) sheets represent a common high-risk load: their large dimensions constrain grasp and line-of-sight, promote trunk flexion and asymmetric postures, and increase pushing/pulling and repositioning demands during delivery and cutting. International ergonomic frameworks emphasize eliminating manual carrying when reasonably practicable and using engineering controls to keep handling within human capabilities (ISO 11228-1:2021; Santos et al., 2025).

This work summarizes an occupational ergonomics intervention carried out in J&G Hardware store in Cuauhtémoc, Chihuahua, Mexico, to evaluate and redesign a critical task: Drywall sheets transport and positioning from storage to the point of service. A low-cost auxiliary transport device was designed, built, and evaluated using rapid ergonomic methods, with pre/post comparison focused on measurable exposure reduction and practical feasibility for a small business.

2. OBJECTIVES

2.1 General objective:

To design, build, and ergonomically evaluate an auxiliary transport device for drywall sheets in the J&G Hardware Store to eliminate manual carrying, reduce WMSD risk, and improve task performance.

2.2 Specific objectives:

- 1) Identify and document ergonomic risks in the existing task (awkward postures, excessive force, repetitive handling).
- 2) Apply standardized ergonomic assessment tools to the baseline task (HSE Manual handling assessment charts — the MAC tool).
- 3) Translate assessment findings into concrete design requirements (handle height, wheel/rolling resistance, load stabilization).
- 4) Verify risk reduction after implementing the device using post-intervention scoring and qualitative observation.

2.3 Scope and delimitation

The study focused on one high-exposure activity within a single retail facility: lifting, transporting, and positioning standard drywall sheets (tablaroca) during customer service. The evaluation emphasized physical/biomechanical risk factors (posture, force, repetition, and task duration). It did not quantify long-term health outcomes, psychosocial factors, or productivity impacts beyond task-level observations. Because the post-intervention package available for direct comparison was the MAC tool, this method was treated as the primary quantitative pre/post indicator. At the same time, REBA were reported as baseline prioritization tools.

3. METHODOLOGY

A cross-sectional field evaluation was completed the workflow was mapped and documented with photographs and direct observation. Baseline risk was assessed using: (a) REBA (Rapid Entire Body Assessment) (McAtamney & Hignett, 1995), to characterize whole-body postural load during lifting/carrying and repositioning; and (b) the HSE MACTool (Manual handling assessment charts) (HSE, 2026) to estimate exposure to repetitive upper-limb risk factors, generating an exposure score and urgency level.

Design requirements were derived from the assessment results and ergonomic design guidance for manual handling and push/pull tasks: (i) handle height positioned between hip and elbow height to maximize push capability and reduce shoulder/back loading; (ii) low rolling resistance using wheels of adequate diameter and bearings; and (iii) load stabilization to maintain control of the center of mass and reduce awkward gripping and trunk asymmetry. A prototype device was constructed and introduced to replace manual carrying with assisted transport. Postintervention evaluation repeated the MAC tool and documented qualitative changes in posture and task execution.

4. RESULTS

Baseline evaluations indicated high risk and the need for prompt intervention. The REBA score reached 13 (very high risk; immediate action required) (Figure 1).

In the MAC tool before the intervention, the exposure score related to the lifting and carrying operation was 20, equivalent to the “3” action category (13-20) (Pinder, 2002), which warrants corrective actions as soon as possible. (Figure 2).

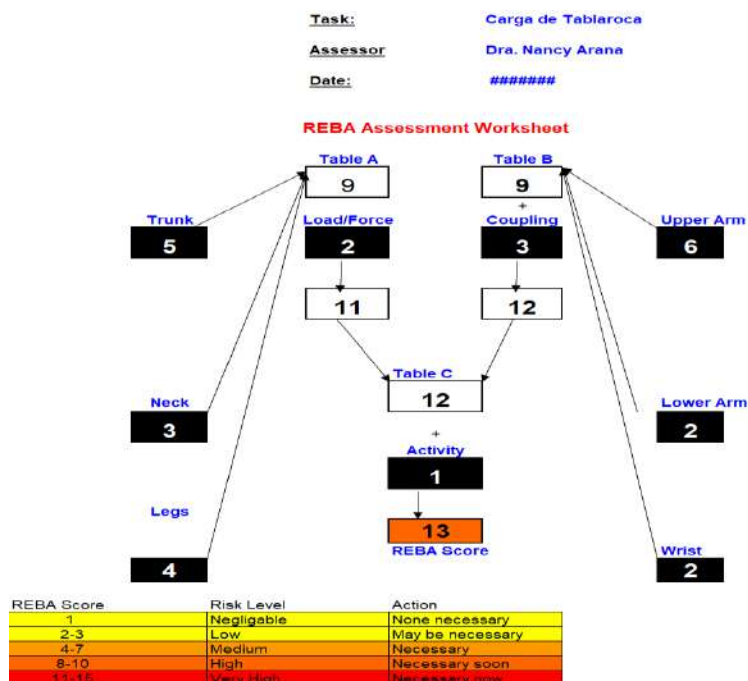


Figure 1. REBA worksheet (baseline), final score = 13 (very high risk).

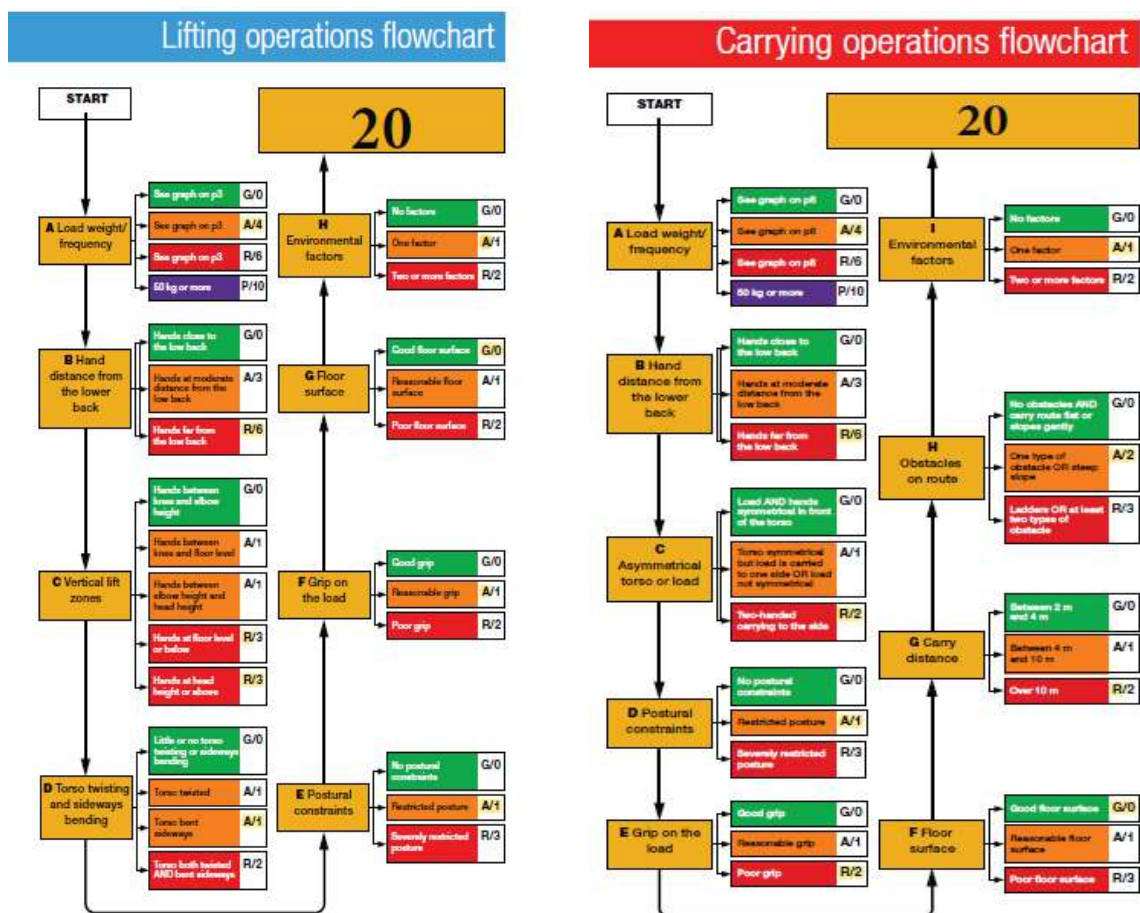


Figure 2. MAC Tool Lifting and Carrying Operations flowchart (Source: HSE, 2026).

An auxiliary transport device was designed and fabricated (Figure 3),

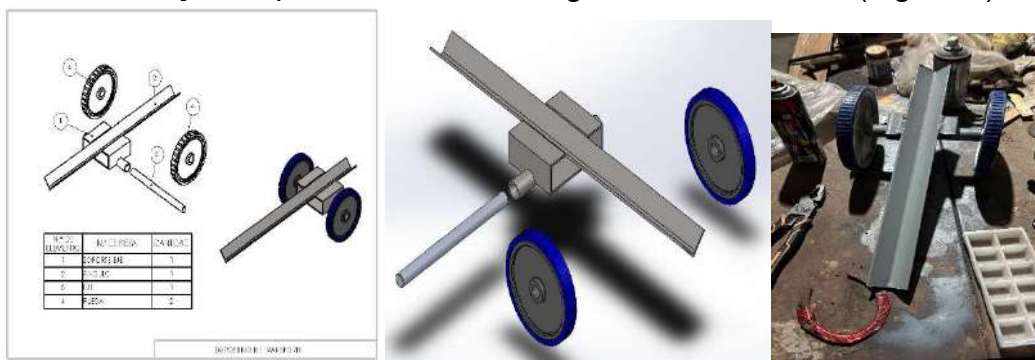


Figure 3. Auxiliary transport device design and fabrication (Source: Authors).

When the device was finished, manual carrying was replaced by assisted transport and controlled push/pull handling (Figure 4).



Figure 4. Task done using the proposed auxiliary transport device (source: authors).

The post-intervention MAC exposure in the lifting operation decreased to 12, and in the carrying operations to 9, equivalent to the “2” action category (5-12) (Pinder, 2002), which warrants corrective actions in a short period of time (Figure 5).

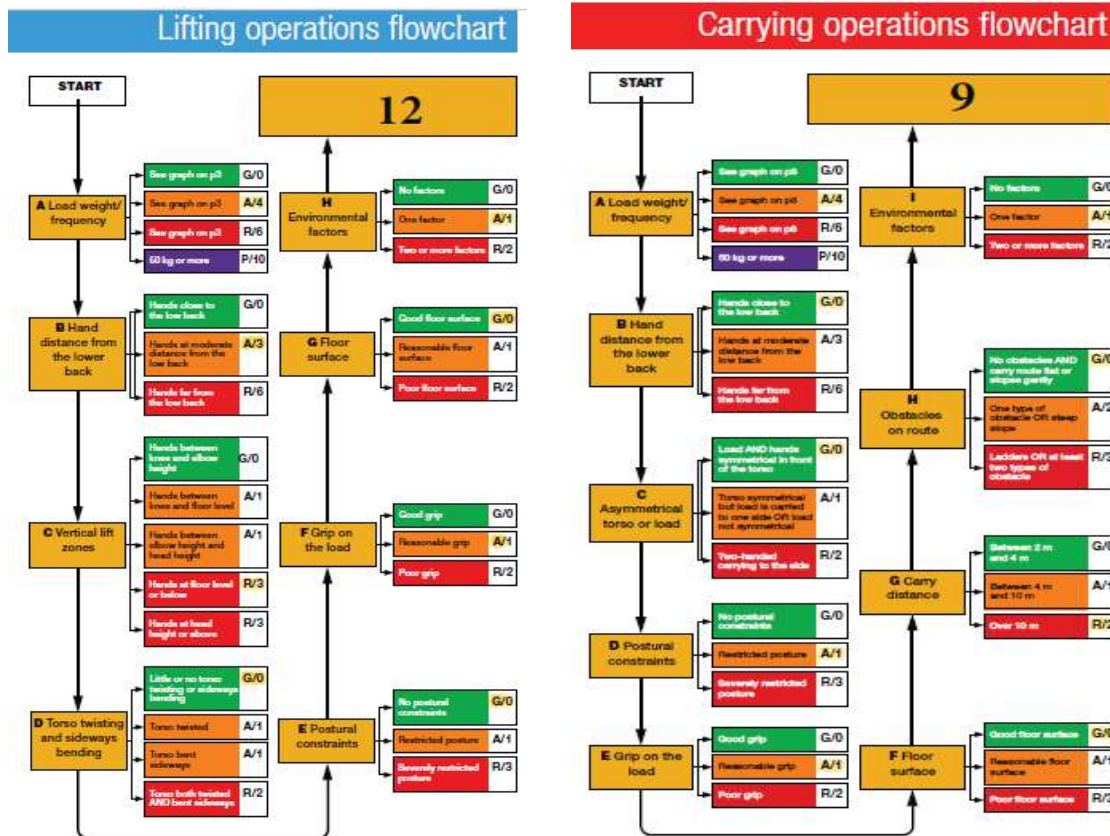


Figure 5. MAC Tool Lifting and Carrying Operations flowchart (post-intervention) (Source: HSE, 2026).

Relative to the baseline exposure score (20), the reduction ranged from 40% to 55%, indicating a substantial reduction in the risk of musculoskeletal injuries. Qualitatively, operators showed less trunk flexion and fewer asymmetric grips, with improved load stability during transport.

Using the basic checklist of manual handling of loads based on ISO 11229-1, ISO 11228-2, ISO/TR 12295, and the INSST Load Lifting Guide (Diego-Mas, 2015), the initial assessment had 18 items, mentioned next:

1. The need for manual handling of the load can be eliminated through the implementation of technical or organizational measures. This would significantly reduce the risk of musculoskeletal injuries.
2. The load's width exceeds the worker's shoulder width, making it difficult to handle and potentially leading to awkward postures and imbalance. This condition increases the risk of musculoskeletal injuries.
3. The load's height obstructs the worker's view, increasing the risk of tripping, collisions, and loss of control.
4. The grip quality is poor or inadequate, making handling difficult, increasing the need for force, and raising the risk of the load falling or slipping.
5. The load's center of gravity is misaligned with its geometric center, which can cause imbalances and increase the effort required to grip and carry it.
6. The heaviest part of the load is farther from the body, increasing the lever arm and requiring greater effort to lift, thus increasing the risk of lower back injuries.

7. The load has sharp edges or points, increasing the risk of hand or arm injuries during handling.
8. The effort required for handling is significant, increasing muscle fatigue and the risk of injury, especially if mechanical aids or adequate breaks are not used.
9. Twisting or bending the torso is necessary during handling, which overloads the spine and increases the risk of lower back injuries.
10. Unexpected or sudden movements occur, which can destabilize the worker and increase the risk of falls or muscle strain.
11. Unstable postures are adopted during handling, compromising the worker's balance and increasing the likelihood of falls or strain.
12. The space is insufficient, forcing users to make difficult turns, bends, or maneuvers. This increases the risk of awkward postures and muscle strain, raising the possibility of injury.
13. Handling is performed outdoors, under adverse weather conditions such as rain or wind, which can reduce visibility and increase the risk of slips or loss of control of the load.
14. The worker's hands must be positioned above 175 cm or below the ground at foot level, which can lead to awkward postures and increase the risk of muscle strain.
15. The vertical distance between the origin and destination of the load is greater than 175 cm, which increases the risk of strain on the back and shoulders, especially when lifting or setting down the load.
16. The transport distance is greater than 20 meters, which increases worker fatigue and the effort required to complete the task.
17. The work pace is dictated by the demands of the process, which can limit the ability to take breaks and increase the risk of fatigue and overexertion.
18. The worker lacks adequate training on the task and handling, which may lead to adopting incorrect postures or making unnecessary efforts that increase the risk of injury.

Post-intervention assessment reduces the items to 9, based on the elimination of 50% of the items (1, 2, 8, 9, 11, 12, 14, 15 and 18) due to the prototype use.

Table 1 summarizes the main design features and the ergonomic rationale grounded in international best practice (ISO, 2021; Kee, 2022) (e.g., minimizing manual carrying, reducing required force through rolling resistance management, and supporting neutral postures during push/pull).

Table 1. Key design features and ergonomic rationale.

Design feature	Ergonomic rationale (aligned with international principles)
Handle height between hip and elbow	Supports neutral shoulder posture and improves push capability while reducing shoulder and low-back loading (ISO, 2021).
Low rolling resistance (adequate wheel diameter + bearings)	Reduces initial and sustained push/pull forces required to move the load,

	lowering biomechanical demand (Iwakiri et al., 2024).
Load stabilization/support frame	Improves control of the center of mass and reduces asymmetric grips and trunk rotation during transport.
Assisted transport replaces manual carrying	Engineering control that reduces exposure to awkward postures and manual carrying, consistent with evidence that ergonomic interventions reduce WMSD pain and risk (Santos et al., 2025).
Simple construction for SMEs	Facilitate adoption in small businesses where resources are limited; supports pragmatic implementation and continuous improvement.

5. CONCLUSIONS

The project demonstrates that targeted engineering control can markedly reduce ergonomic exposure in MMH tasks involving bulky construction materials in retail settings. Baseline handling of drywall sheets showed very high postural risk (REBA 13) and medium repetitive-task exposure (MAC 20). The auxiliary transport device reduced MAC exposure to low levels (9-13), representing a 40–55% reduction versus baseline. The intervention provides a practical, low-cost pathway for risk reduction in small enterprises, complementing administrative measures (training, housekeeping, route planning) and aligning with international manual-handling principles (ISO 11228-1:2021 (ISO, 2021)). Future work should quantify push/pull forces under different floor conditions, evaluate user acceptability and productivity metrics over longer periods, and repeat whole-body scoring after implementation to document sustained postural benefits.

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RISK ASSESSMENT OF MUSCULOSKELETAL AND BIOMECHANICAL ISSUES IN THE MANUAL HANDLING OF LOADS IN THE AQUACULTURE SECTOR

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Resumen: La acuicultura en Sinaloa es un pilar estratégico para la seguridad alimentaria nacional, operando mediante una red de 907 unidades de producción que consolidan al sector camaronero como motor económico en el noroeste de México (FAO, 2024; CESASIN, 2023). No obstante, la intensidad operativa en las plantas procesadoras plantea desafíos críticos en salud ocupacional. Objetivo: Evaluar el riesgo biomecánico y la compresión lumbar en trabajadores dedicados al levantamiento manual de unidades de 50 kg, bajo una perspectiva de ergonomía física y diseño de sistemas. La metodología que se realizó es un estudio descriptivo transversal en una planta procesadora de Guasave. El análisis postural integró el método RULA. Se evaluó el discomfort mediante la escala de Corlett y Bishop, auditando el cumplimiento de la NOM-036-1-STPS-2018 bajo condiciones de fatiga por jornadas prolongadas. Se espera el resultado de las metodologías aplicadas. Las puntuaciones RULA (Nivel 7) confirmaron una falla crítica de seguridad derivada de la combinación de peso excesivo, posturas forzadas y tiempos de exposición extensos. Conclusiones: La ergonomía en el diseño de estaciones es vital para reducir la siniestralidad. Se establece como imperativa la reestructuración de las cargas a 25 kg e implementación de controles de ingeniería para garantizar un entorno laboral y normativo.

Palabras clave: Estudio de tiempos y movimientos, RULA, productividad, mejora continua

Relevancia para la ergonomía: este estudio contribuye al análisis aplicado de la ergonomía en entornos industriales, demostrando cómo la intervención ergonómica puede reducir riesgos musculoesqueléticos y mejorar la eficiencia operativa en sistemas productivos.

Abstract: Aquaculture in Sinaloa is a strategic pillar of national food security, operating through a network of 907 production units that establish the shrimp sector as an economic driver in northwestern Mexico (FAO, 2024; CESASIN, 2023).

However, the operational intensity in processing plants poses critical challenges in occupational health. Objective: To assess biomechanical risk and lumbar compression in workers engaged in the manual lifting of 50-kg units, from the perspective of physical ergonomics and systems design. The methodology employed was a descriptive cross-sectional study at a processing plant in Guasave. Postural analysis incorporated the RULA method. Discomfort was assessed using the Corlett and Bishop scale, auditing compliance with NOM-036-1-STPS-2018 under conditions of fatigue due to prolonged work shifts. Results from the applied methodologies are pending. The RULA scores (Level 7) confirmed a critical safety failure resulting from the combination of excessive weight, forced postures, and prolonged exposure times. Conclusions: Ergonomics in workstation design is vital for reducing accidents. It is imperative to restructure loads to 25 kg and implement engineering controls to ensure a safe and compliant work environment.

Keywords: ergonomics, time and motion, RULA, productivity, continuous improvement

Relevance to Ergonomics: This study contributes to the applied analysis of ergonomics in industrial settings, demonstrating how ergonomic intervention can reduce musculoskeletal risks and improve operational efficiency in production systems.

1. INTRODUCTION

The aquaculture industry has established itself as a strategic pillar of global food security, providing not only essential nutrients but also livelihoods for millions of people worldwide (FAO, 2024). In this context, Mexico stands out primarily for the state of Sinaloa. This state, characterized by a warm subhumid climate and advanced technological infrastructure, leads the nation in food production, employing more than 165,000 people and leveraging its privileged proximity to international markets (Sinaloa Ministry of Economy, 2023).

Aquaculture in Sinaloa is carried out through a network of 907 Aquaculture Production Units (APUs) covering more than 67,000 hectares of water surface, where crustacean farming predominates under semi-intensive and intensive systems (CESASIN, 2023). The transition to biosecure and bio-eco-efficient farming technologies has enabled the state to maintain its competitiveness in the face of health challenges, consolidating the shrimp sector as a key economic driver for the country's northwestern region (SENASICA, 2022).

The municipality of Guasave is a critical hub in this production chain. With a 50-kilometer coastline and more than 24,000 hectares of bays, the region combines traditional fishing with a robust aquaculture industry. Currently, Guasave is home to approximately 100 shrimp farms with an operational area of 5,500 hectares (Guasave City Council, 2024).

In the aquaculture sector, economic units operate under long shifts ranging from 8 to 16 hours, where the inadequate design of workstations and the manual handling

of heavy loads compromise safety and productivity. Despite the economic significance and technological advancements in cultivation processes, the processing and packaging phase—where high-tonnage loads are handled—presents significant ergonomic challenges that compromise workers' occupational health. This aspect motivates the present analysis and assessment of the biomechanical risks to which workers are exposed when manually lifting 50-kg units in the packing warehouse, from the perspective of physical ergonomics and system design.

2. OBJECTIVES

To assess the risk of musculoskeletal disorders and the biomechanical load associated with manual handling of loads in the packaging area of an aquaculture company, using postural and normative analysis methods, with the aim of proposing ergonomic intervention strategies to ensure occupational health.

3. METHODOLOGY

This study employs a quantitative approach with a descriptive scope and a cross-sectional design. The research is structured in four phases:

1: Process Characterization and Field Data Collection

A task analysis will be conducted in the packaging area using direct observation and process flowcharts. Data will be collected on critical variables: load weight, lifting frequency, carrying distances, and length of the workday. To record postures, photographs and videos will be taken at 90° and 45° angles to avoid parallax errors in the subsequent analysis.

2: Assessment of Postural Factors

The RULA (Rapid Upper Limb Assessment) method will be applied to evaluate workers' exposure to risk factors that cause high postural loads on the upper limbs, neck, and trunk. Work cycles with the greatest ergonomic challenges will be selected at the forming and coating stations.

The Corlett and Bishop Questionnaire will be applied; this qualitative tool will be used to map the areas of greatest discomfort and perceived fatigue reported by operators, allowing for the correlation of biomechanical findings with subjective symptoms.

3: Analysis of the Regulatory Framework

The Official Mexican Standards (NOM) of the Ministry of Labor and Social Welfare (STPS) will be applied to the workstation, and NOM-036-1-STPS-2018 will be analyzed using a standard checklist to determine the unit's level of legal compliance.

4: Design of Intervention Strategies

The Hierarchy of Risk Control will be applied to design improvement proposals. These will be classified as follows: Engineering Controls: Redesign of workstations, use of mechanical aids (vacuum lifters, scissor lifts).

4. RESULTS

4.1 Process Characterization and Field Survey

The shrimp processing plant is one of the most important in the municipality. A tour of the facility was conducted to observe the production process, which consists of seven areas (raw material reception, deheading, sorting, resting, freezing, packaging, and cold storage), with all activities designed to ensure product quality.

In the packaging area, the production process consists of 6 operations. Eleven male operators work here, ranging in age from 23 to 45 years old. Their workday lasts 8 to 11 hours, Monday through Saturday. The production process in the packaging area is shown in Figure 1.

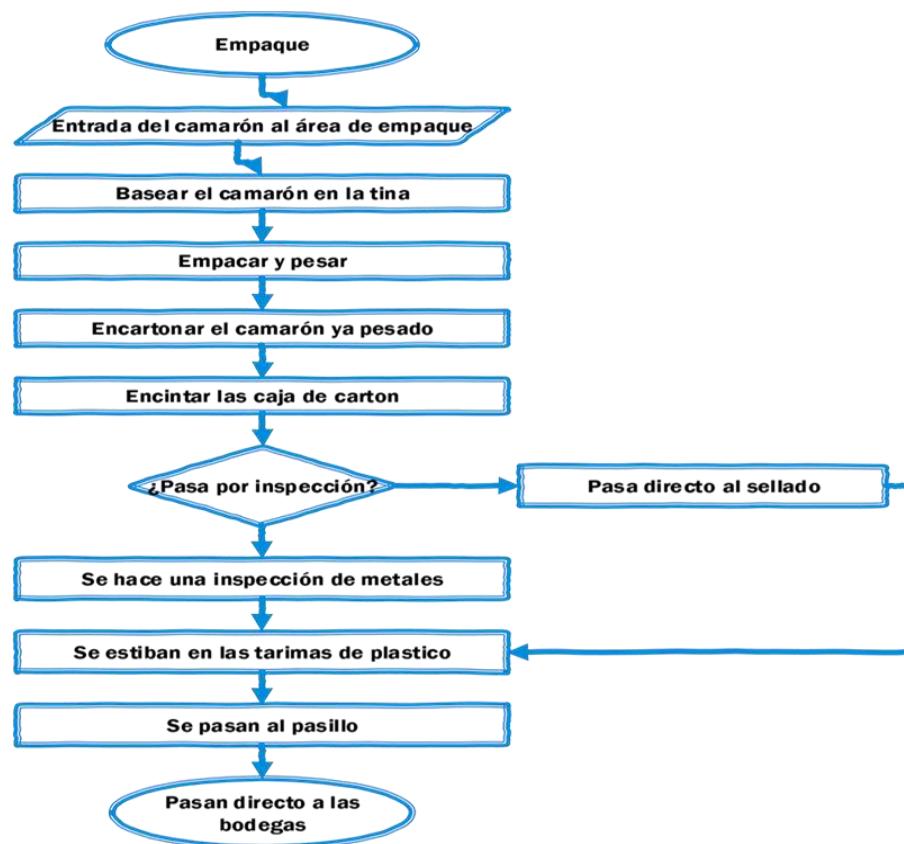


Figure 1: Flowchart of operations in the packaging área

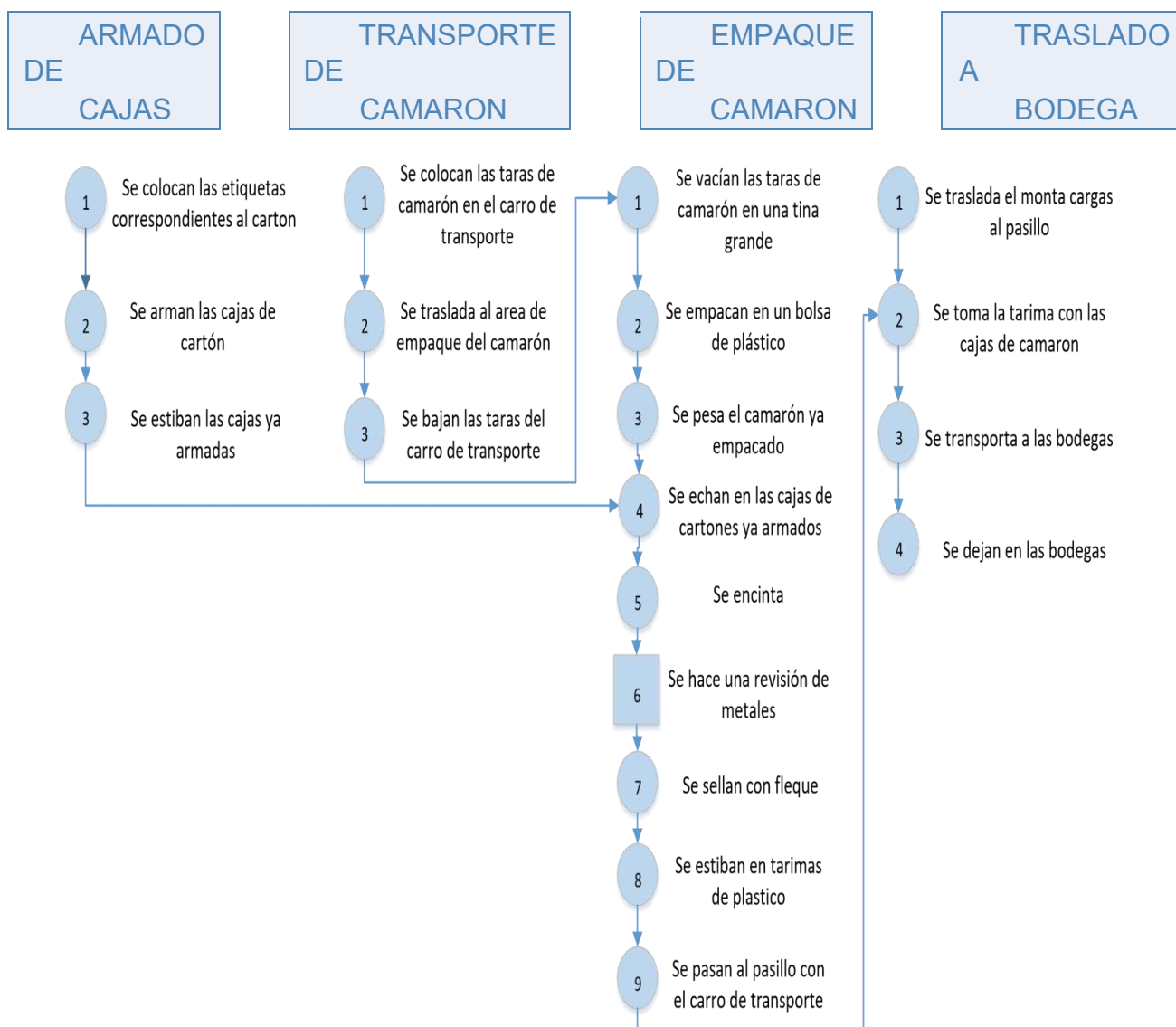


Figure 2: Flowchart of the packaging área

4.1.1 Data Collection

Boxes of frozen shrimp are lifted from the floor onto a conveyor belt at a height of 110 cm. The belt is used for metal detection, after which the boxes are sealed and stored in the finished goods warehouse.

- Standard weight: 50 kg per box.
- Lifting frequency: 6 lifts per minute.
- Transport distance: 2 meters.
- Workday duration: 8 to 11 hours.



Figure 3. Shrimp packaging process, box handling. (Station 1)



Figure 4. Shrimp packaging process, box handling. (Station 2)

To record the positions, photographs and video footage will be taken from angles of 90° and 45° to avoid parallax errors in the subsequent analysis.

4.2. Evaluation of Postural Methods

The RULA (Rapid Upper Limb Assessment) method will be applied to evaluate workers' exposure to risk factors that cause high postural loads on the upper limbs, neck, and trunk. Work cycles with the greatest ergonomic challenges will be selected at the shaping and coating stations.

The Corlett and Bishop Questionnaire will be administered; this qualitative tool will be used to map the areas of greatest discomfort and perceived fatigue among operators, allowing for the correlation of biomechanical findings with subjective symptoms.

Based on the research and behavioral observations, the postures posing the greatest risks to operators were identified. This formed the basis for the evaluation of postural methods, which was Station 2.

Método R.U.L.A. Hoja de Campo

A. Análisis de brazo, antebrazo y muñeca

Paso 1: Localizar la posición del brazo

Si el hombro está elevado: +1
Si el brazo está abducido (despegado del cuerpo): +1
Si el brazo está apoyado o sostenido: -1

Puntuación brazo: 4

Paso 2: Localizar la posición del antebrazo

Paso 2a: Corregir...
Si el brazo cruza la línea media del cuerpo: +1
Si el brazo sale de la línea media del cuerpo: +1

Puntuación antebrazo: 3

Paso 3: Localizar la posición de la muñeca

Paso 3a: Corregir...
Si la muñeca está doblada por la línea media: +1

Puntuación muñeca: 2

Paso 4: Giro de muñeca

Si la muñeca está en el rango medio de giro: +1
Si la muñeca está girada próxima al rango final de giro: +2

Puntuación giro de muñeca: 1

Paso 5: Localizar puntuación postural en Tabla A

Utilizar valores de pasos 1, 2, 3 y 4 para localizar puntuación postural en Tabla A

Puntuación postural A: 4

Paso 6: Añadir puntuación utilización muscular

Si la postura es principalmente estática (pausas superiores a 1 min.) o si puede repetidamente la acción (4 veces/min. o más): +1

Puntuación muscular: 0

Paso 7: Añadir puntuación de la Fuerza / Carga

Si carga o esfuerzo < 2 Kg. intermitente: +0
Si es de 2 a 10 Kg. intermitente: +1
Si es de 2 a 10 Kg. estático o repetitivo: +2
Si es una carga > 10 Kg. o vibrante o súbita: +3

Puntuación fuerza/carga: 3

Paso 8: Localizar fila en Tabla C

Ingresar a Tabla C con la suma de los pasos 5, 6 y 7

Puntuación final muñeca, antebrazo y brazo: 7

Empresa: Molino Hernando de Villafañe Fecha:
Puesto / Sección: Empacador.

B. Análisis de cuello, tronco y piernas

Paso 9: Localizar la posición del cuello

Paso 9a: Corregir...
Si hay rotación: +1; si hay inclinación lateral: +1
Si hay extensión, cualquier ángulo: +1

Puntuación cuello: 4

Paso 10: Localizar la posición del tronco

Paso 10a: Corregir...
Si hay torsión: +1; si hay inclinación lateral: +1

Puntuación tronco: 4

Paso 11: Localizar la posición de las piernas

Paso 11a: Corregir...
Si piernas y pies adyacentes y equilibrados: +1
Si no: +2

Puntuación piernas: 2

Paso 12: Localizar puntuación postural en Tabla B

Utilizar valores de pasos 9, 10 y 11 para localizar puntuación postural en Tabla B

Puntuación postural B: 7

Paso 13: Añadir puntuación utilización muscular

Si la postura es principalmente estática (pausas superiores a 1 min.) o si puede repetidamente la acción (4 veces/min. o más): +1

Puntuación uso muscular: 0

Paso 14: Añadir puntuación de la Fuerza / Carga

Si carga o esfuerzo < 2 Kg. intermitente: +0
Si es de 2 a 10 Kg. intermitente: +1
Si es de 2 a 10 Kg. estático o repetitivo: +2
Si es una carga > 10 Kg. o vibrante o súbita: +3

Puntuación fuerza/carga: 3

Paso 15: Localizar columna en Tabla C

Ingresar a Tabla C con la suma de los pasos 12, 13 y 14

Puntuación final cuello, antebrazo y brazo: 10

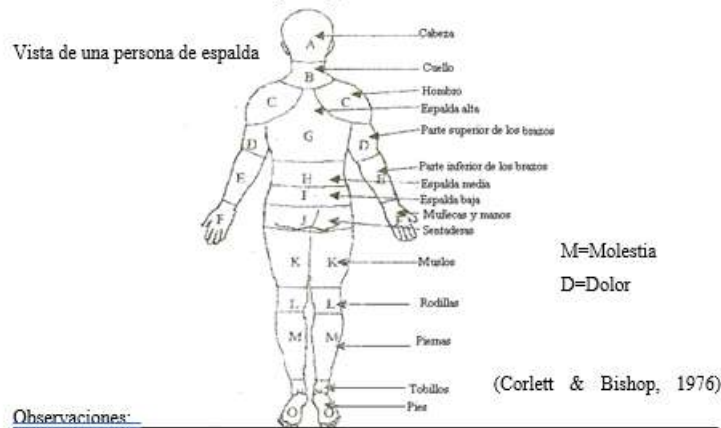
Referencias:
Observador: Valeria Alejandra Castro Armenta. Firma:

Puntuación Final: 1 ó 2: Aceptable; 3 ó 4: Ampliar el estudio; 5 ó 6: Ampliar el estudio y modificar pronto; 7: estudiar y modificar inmediatamente

Figure 5. Application of the RULA method at Station 2

The application of the RULA method yields a score of 7, indicating that the workstation must be reviewed and the work procedures modified immediately.

Mapa de molestias para las diferentes partes del cuerpo.
 Marque con una cruz las partes del cuerpo donde sienta alguna molestia o dolor y
 numérelas en orden ascendente según su grado de molestia o dolor



	ENTRADA						SALIDA					
A												
B	M	M	M	M	D	D	M	M	M	D	D	D
C	M	M	M	D	D	D	M	M	D	D	D	D
D	M	M	M	D	M	D	M	M	D	D	D	D
E												
F												
G	M	M	D	D	D	D	M	D	D	D	D	D
H	M	M	M	D	D	D	M	M	D	D	D	D
I	M	M	M	D	D	D	M	M	D	D	D	D
J	M	M	M	D	D	D	M	M	D	D	D	D
K	M	M	M	D	D	D	M	M	D	D	D	D
L	M	M	D	D	D	D	M	M	D	D	D	D
M												
N												
O												

Figure 6. Application of the Corlett and Bishop Method, Station 2

It is noted that starting on the second day of work, the operator reports discomfort, and by the end of the day, pain sets in. With four days remaining in the week, the operator reports physical and mental fatigue due to the work performed during overtime shifts. The Corlett and Bishop method indicates that physical fatigue is generated by the operations being performed.

4.3 Implementation of the Official Mexican STPS Standards

Table 1. Implementation of the Official Mexican STPS Standards

List of official Mexican Standards applied to the production process of the company
Company: Acuicola Los Ahumada
Line of business: área de empaque

Date: ago 22,2025			
Standard	Yes	No	Observations
Official Mexican STANDARD NOM-011-STPS-2001, Safety and hygiene conditions in workplaces where noise is generated.		X	In the facilities there is no mediator to reduce the noise that the machinery generates, in the same way the worker does not use personal protection.
Official Mexican STANDARD NOM-001-STPS-2008, Buildings, premises, facilities and areas in workplaces-Safety conditions.		X	The company does not have security conditions in any of its work areas.
Official Mexican STANDARD NOM-004-STPS-1999, Protection systems and safety devices in machinery and equipment used in workplaces.		X	The operators do not have any protection when using the machinery to carry out their activities. Some personal protective equipment is not adequate for the type of activity they perform.
Official Mexican STANDARD NOM-030-STPS-2009, Preventive health and safety services at work-Functions and activities.		X	Employees do not have preventive health and safety services within the company.
Official Mexican STANDARD NOM-024-STPS-2001, Vibrations-Safety and hygiene conditions in the workplace.		X	Employees are exposed to high levels of vibration without any vibration.
NOM-016-STPS-1993, Relative to safety and hygiene conditions in workplaces regarding ventilation.		X	The personnel is exposed to high levels of humidity without having any means to regulate ventilation.

Table 2. Application of the NOM-036-STPS-2018

Evaluation NOM-036-STPS-2018: Manejo de Carga			
	Punto Clave de la Norma	Assessment (Meets / Does Not Meet)	Observations Based on the Photograph
1	Maximum Weight Limit (Men: 25 kg)	Non-compliant	The box weighs 50 kg; this is double the legal limit for a single worker. (
2	Lifting technique (bending at the knees)	Non-compliant	The operator bends at the waist (hunched back) and keeps the knees partially extended
3	Distance from the load to the body	Not fulfilling	When lifting from the ground, the load moves away from the center of gravity, increasing the lever arm.

4	When lifting from the ground, the load moves away from the center of gravity, increasing the lever arm.	Not fulfilling	The lift is performed from the floor (outside the comfort zone: knees to shoulders).
5	Work surface and footwear	Complies / at risk	Rubber footwear (boots) is visible, but the floor is wet, which increases the risk of slipping while carrying a heavy load.
6	Load handling	Not fulfilling	Wet or cold cardboard boxes without handles are difficult to grip securely and require more friction.
7	Use of assistive devices	Not fulfilling	The operator performs the task entirely by hand, without the aid of lift tables or skids at that point.
8	Rotation and breaks	Not observed	The mentioned workday from 8 a.m. to 3 p.m. suggests accumulated fatigue, which exacerbates the posture shown.

4.4 Design of Strategies

Based on the analysis, a proposal for improvement is developed to make the operation more effective.

Proposed Improvements:

- Implement task rotation to limit continuous exposure to this posture
- Consider a height-adjustable table or an ergonomic workstation. Adjust the height of the work table to the operator's elbow height (approx. 90–105 cm)
- Provide adequate breaks: Ensure that workers have regular and sufficient breaks to recover from muscle fatigue.
- Train workers: Provide training to workers on safe and efficient work techniques to reduce risk
- Monitor and supervise: Monitor and supervise the task and the workers to ensure that corrective measures are being implemented
- The packaging area was redesigned to optimize space utilization and improve the workstations.
- The workflow was reversed so that operators now pass the shrimp box through each workstation.
- Lighting and ventilation at the workstation were improved to fatigue and stress.

The changes made to the optimized workstation were as follows:

- Tools and materials were reorganized to reduce the movements and actions required to complete tasks.
- The packaging area was redesigned to optimize space utilization and improve the workstations.
- The workflow was reversed so that operators now pass the shrimp box through each workstation.

- Lighting and ventilation at the workstation were improved to reduce operator fatigue and stress.
- Reduced operator fatigue and stress. increased efficiency and productivity in the production process.

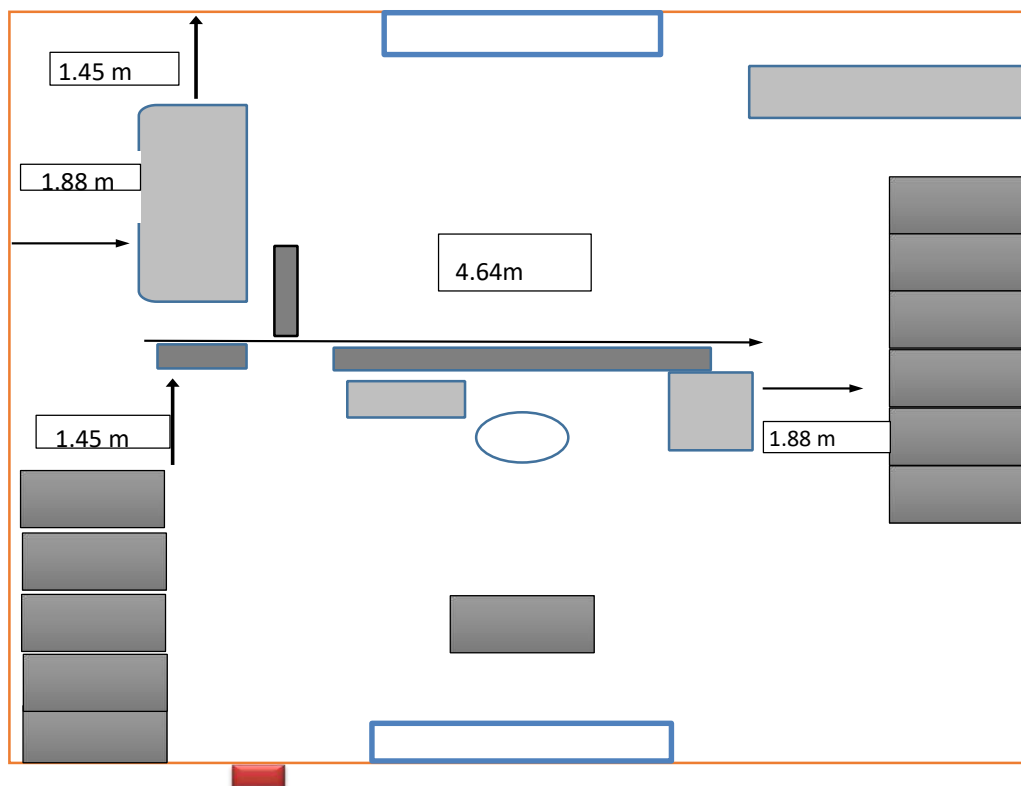


Figure 7. Current layout

5. DISCUSSION/CONCLUSIONS

The analysis leads to a proposal for improvement. Based on the comprehensive assessment conducted at the aquaculture facility, the following conclusions are drawn, which validate the relevance of ergonomic intervention and the design of work systems. The Strategic and Regulatory Diagnosis is essential for field visits and operational analysis, as it allows us to identify that, while the company has a solid competitive position at the national level, it has critical weaknesses in its ergonomic infrastructure.

Compliance with Mexican Official Standards (NOM) should not only be interpreted as a legal requirement but also as a strategic advantage that increases profitability by reducing costs associated with workplace accidents and improving process efficiency. It is concluded that workstation design must be based on strategies that harmonize the operator's anthropometric and biomechanical capabilities with production objectives, ensuring a work environment that promotes performance and well-being. The Impact on Productivity: Improvements in the

packaging area demonstrate that ergonomics is a driver of optimization. By redesigning workstations based on scientific criteria, the foundation is laid for a sustained increase in production, eliminating downtime resulting from muscle fatigue and poor posture.

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RELATIONSHIP BETWEEN TECHNOSTRESS, WORKING CONDITIONS AND IMPACT ON MENTAL HEALTH IN FEMALE UNIVERSITY PROFESSORS.

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RESUMEN: Introducción: El término tecnoestrés, se describe como un estado psicológico negativo producto de la incapacidad de adaptarse de forma saludable al uso intensivo de nuevas tecnologías, sobre todo después de la Pandemia de COVID 19.

A pesar de que el tecnoestrés ha sido reconocido mayormente en diferentes actividades donde existe un uso laboral extensivo de las tecnologías de información y comunicación (TIC), hoy en día con el auge de las tecnologías, existe una necesidad de su uso en el campo educativo, situación que puede estar asociada al desarrollo del tecnoestrés en docentes con un enfoque de género.

En un actual contexto, caracterizado por el aprendizaje en línea, como las clases virtuales y una alta dependencia de dispositivos, donde los centros educativos, al adoptar plataformas digitales y exigir habilidades tecnológicas, introducen nuevos riesgos psicosociales en los docentes, lo cual ha propiciado a un desajuste entre las demandas tecnológicas y las capacidades o recursos del estudiante, y como resultado, generando tecnoestrés en docentes.

Objetivos: Analizar la relación entre los niveles de Tecnoestrés en el trabajo y condiciones laborales post pandemia propios de la actividad docente y su impacto en la salud mental en profesoras universitarias

Métodología: Se trata de una investigación con alcance transversal, de tipo correlacional, con muestreo no probabilístico intencional. Participaron 179 profesoras universitarias de una institución de educación superior pública.

a) Instrumentos:

Escala de evaluación de Tecnoestrés docente para profesores universitarios, la Escala de evaluación de ansiedad y depresión de Goldberg y el Cuestionario sobre condiciones de trabajo.

A los profesores que aceptaron se envió una liga del cuestionario a su correo proporcionado a través de la liga de la plataforma Survey Monkey. Se les pidió firmar carta de consentimiento informado y se obtuvo el aval del comité de Ética de la facultad con número FESZ/DEPI/CE/008/21.

Resultados: Se observaron correlaciones significativas positivas entre los distintos tecno estresores con condiciones ergonómicas y de trabajo relacionadas con el uso de la tecnología. Hubo asociación del tecnoestrés con la presencia de depresión y ansiedad y además se encontraron asociaciones del tecnoestrés con el tipo de silla y de escritorio que se usa.

Conclusiones: Los resultados hacen ver la necesidad de implementar programas de formación tecnológicas que tengan un enfoque de género y dirigidos a las docentes y exista un monitoreo su bienestar tecnológico, de lo contrario, se puede afectar su salud mental y bienestar. Se deben generar propuestas de mejora organizacional y ergonómica que permitan mejorar los ambientes laborales y desarrollar procesos.

Palabras clave: tecnoestrés, profesoras universitarias, mujeres.

Relevancia para la ergonomía: El presente trabajo aporta a la ergonomía cognitiva por una parte un instrumento validado para evaluar la presencia de tecnoestresores en los sitios de trabajo, además con un enfoque de género da información sobre los impactos en la salud mental de los tecnoestresores generados por el uso de TIC en las actividades de docentes universitarias que coadyuven a la salud mental de las docentes.

ABSTRACT: Introduction: The term technostress is described as a negative psychological state resulting from the inability to adapt healthily to the intensive use of new technologies, especially after the COVID-19 pandemic.

Although technostress has been recognized primarily in various activities involving extensive use of information and communication technologies (ICTs), today, with the rise of these technologies, there is a need for their use in the educational field, a situation that may be associated with the development of technostress in teachers with a gender point of view.

In the current context, characterized by online learning, such as virtual classes and a high dependence on devices, educational institutions, by adopting digital platforms and demanding technological skills, introduce new psychosocial risks for teachers. This has led to a mismatch between technological demands and students' capabilities or resources, resulting in technostress among teachers.

Objectives: To analyze the relationship between levels of technostress at work and post-pandemic working conditions specific to teaching and their impact on the mental health of female university professors.

Methodology: This is a cross-sectional, correlational study, with purposive non-probability sampling. Participants included 179 female university professors from a public higher education institution.

Instruments: The Technostress Assessment Scale for University Professors, the Goldberg Anxiety and Depression Scale, and the Questionnaire on Working Conditions.

Professors who agreed to participate were sent a link to the questionnaire via the email address provided through the SurveyMonkey platform. They were asked to sign an informed consent form, and the study received approval from the faculty's Ethics Committee (number FESZ/DEPI/CE/008/21).

Results: Significant positive correlations were observed between the various technostressors and ergonomic and working conditions related to technology use. Technostress was associated with depression and anxiety, and was also linked to the type of chair and desk used.

Conclusions: The results highlight the need to implement technology training programs with a gender focus, specifically designed for female teachers, and to monitor their technological well-being. Otherwise, their mental health and well-being may be negatively impacted. Organizational and ergonomic improvement proposals should be developed to enhance work environments and to improve processes.

Keywords: technostress, university teachers, women

Relevance to ergonomics: This work provides, on the one hand, a validated instrument of cognitive ergonomics to assess the presence of technostressors in the workplace, and, with a gender focus, it provides information on the impacts on the mental health of technostressors generated using ICT in the activities of university teachers.

1. INTRODUCTION

The IEA (International Ergonomics Association) defined ergonomics as “the scientific discipline concerned with understanding the interaction between humans and other elements of a system.” Therefore, today, ergonomic analysis inevitably includes social aspects (Carrasquero, 2009; Soliván, 2023).

Organizational ergonomics examines the optimization of sociotechnical systems, including structures, policies, and processes (Carrasquero, 2009). It covers task organization, role assignment, and resource management. The goal is to improve work structures and processes, thereby boosting operational effectiveness and personal well-being (Vallejo, 2024).

Another area, cognitive ergonomics, deals with mental processes—perception, memory, reasoning, and motor response—that affect interactions between people and system components. This applies to mental workload, decision-making (choosing among options), performance, human-computer interaction, and job stress (IEA, 2025). These points emphasize the importance of ergonomics in organizations to maintain a healthy human-system relationship, as seen in educational institutions.

Currently, these educational institutions have adopted digital platforms, which have required teaching staff to possess technological skills, thus creating new

challenges for educators. This comes with technological demands that can cause a mismatch between person and technology, increasing technological stress, which can lead to technostress.

The term technostress is described as a negative psychological state resulting from the inability to adapt healthily to the intensive use of new technologies. Although technostress has been primarily recognized in various activities involving extensive use of computers and information technologies, today, with the rise of technology, there is a need for its use in the educational field, a situation that may be associated with the development of technostress in teachers (Rodríguez-Vásquez, et al., 2021). In the current context, characterized by online learning, such as virtual classes and a high dependence on devices, educational institutions are. These institutions have adopted digital platforms and are demanding technological skills, introducing new psychosocial risks for teachers. This has led to a mismatch between technological demands and students' capabilities or resources, resulting in technostress among teachers. (Solano, 2025; Araya-Ugarte, 2025).

The existence of technological generators has also been highlighted, including the technological burden, technological invasion, complexity in technology use, insecurity caused by ignorance in technology use, and technological uncertainty (Rodríguez-Vásquez et al., 2021).

Teachers, when working on telework, require new skills that are not necessarily the ones they demonstrate in their traditional work, which contributes to generating new technological and psychological demands that can affect the health of the teachers (Martín, 2020)

However, it has been found that women experience technostress more frequently, despite no differences in ICT skills and abilities between men and women. Nevertheless, a significant gender gap in the percentage of women ICT professionals, with women underrepresented (Makowska-Tłomak, 2024). In a study by Makowska-Tłomak (2024), which aimed to provide evidence that gender is a predictive factor for ICT-related stress, it was found that female workers experience greater stress from ICT use compared to male workers. This can be explained by women's lower self-efficacy when facing ICT challenges, a self-efficacy that is conditioned by gender stereotypes, which perceive women as less competent and less skilled in the technological field.

The study carried out by Rodríguez-Vasquez et al. (2021), which aimed to identify the presence of technology in teachers of higher education, encountered higher levels of depression in professors due to the use of technology, the technological overload and the technological invasion. These mental health effects were higher in women than in men.

Delimitation

This work is carried out within the field of organizational and cognitive ergonomics for the analysis of technostress factors reported as associated with mental health problems among university teachers.

2. OBJECTIVES

This work is developed within the field of organizational and cognitive ergonomics, focusing on the analysis of psychosocial risk factors, specifically technostressors, associated with mental health problems among female university professors.

The specific objectives are:

Analyze how technostress and post-pandemic working conditions affect the mental health of female university professors.

3. METHODOLOGY

This is a cross-sectional, correlational study using purposive non-probability sampling.

a) Population:

179 female university professors from a public university participated. Inclusion criteria: Active faculty members teaching in-person, hybrid, or online classes at the end of the pandemic. Exclusion criteria: Professors with administrative appointments, those on sabbatical or sick leave, or those without teaching loads.

b) Instruments:

- Technostress Assessment Scale for University Professors, comprised of six dimensions (Techno-academic workload, Techno-resources, Techno-interaction and communication, Techno-skills, Techno-invasion, and Techno-institutional support) with five response options, from Never to Very Frequently (Unda, Rodríguez, Tovalín, and Gil-La Orden, 2025).

- Goldberg Anxiety and Depression Scale (1980), a scale with two dimensions (Anxiety and Depressive Symptoms) and five response options (Never to Always), with a total of 10 items.

- Questionnaire on working conditions during the pandemic, developed by the authors, specifically: average hours of technology use for planning academic activities, teaching classes, evaluating, and meetings; ergonomic resources when using technology, such as appropriate chairs, desks, and breaks during the workday when using technology.

c) Procedure:

Professors from nine undergraduate and graduate programs were invited to participate voluntarily in the study through a letter attached to their pay stub and through.

Participants were invited personally in the checkout line. Those professors who accepted were sent a link to the questionnaire via the SurveyMonkey platform to the email address they provided.

They were asked to sign an informed consent form, and the project received approval from the faculty's Ethics Committee (number FESZ/DEPI/CE/008/21, registration FESZCE/21-118-07) and was approved for implementation in 2023.

d) Analysis of results:

Descriptive statistics were used to determine the frequencies of working conditions, and inferential statistics were used to establish bivariate correlations using Spearman's rho (non-parametric correlation test).

4. RESULTS

The participant professors have an average age of 49 and 17 years of teaching experience; 52% report having a partner.

Their educational attainment is distributed as follows: 15% bachelor degree, 10% specialist degree, 43% master degree, and 31% doctorate. 44% worked in the morning shift, 11% the afternoon shift, and the remainder in a mixed shift.

The highest percentage of participants was from the psychology program (24%), followed by nursing (19%), medical doctor (14.5%), dentistry (12.8%), and the rest from six other programs, including postgraduate studies.

A 73% were adjunct professors, and the remainder were full-time. A 80% belong to an incentive program, and 44.1% report having another job.

Regarding activities considered teleworking under Mexican law, 41.3% report working more than three and a half hours a day, attending to work matters using electronic devices, 85% taught at the undergraduate level, 6% at postgraduate studies, and the rest in both.

Average hours spent using electronic devices: planning academic activities, 13 hours per week; teaching online classes, 3.4 hours; evaluating academic activities, 8.37 hours; academic meetings, 4 hours.

About ergonomic conditions, 41% report having an ergonomic chair, 69% a computer desk, 50% reported that their chair allows them to maintain good posture, and 51% indicate that their desks have the right height, and 58% indicated that they take frequent visual breaks.

Related to their mental health, 31% reported medium levels of anxiety and 10% high levels.

As for the work-family relationship, 37% report taking care of their children on Sundays, in three cases (70.4% carry out household work on a daily basis), only 2% report not carrying out these activities.

The teachers inform that in the meantime, the use of an electronic device to plan academic activities is 14.1 hours, more than 3.2 hours teaching, and 4 hours for academic meetings, which in the evening represents more than 20 hours a week. This schedule does not include the use of devices for personal activities, which will significantly increase the time of use.

In terms of psychosocial risk factors, 19.2% reported the presence of difficult students, and 35.6% reported having high levels of academic overload, 35.5% of high mental load due to the use of technology, and 23.7% reported low acceptance of this technology, and low institutional support 32%.

According to the results presented in Table 1, there are significant positive correlations between the various technostressors and working and organizational conditions, as well as with anxiety symptoms.

The correlation with anxiety symptoms is primarily found with the presence of academic technostress and technoinvasion, the latter of which indicates the intrusion of work into family activities, and that increases anxiety symptoms in female university professors.

Table 1 Technostressors, working conditions and health effects

Dimensiones	Suitabl e chair	Suitabl e desk	Break s	Planin g	Classe s	Evaluati on	Meetin gs	Anxiet y
Academic Technology Load	,169*	,225**	,172*	0.145	0.081	0.125	0.067	,180*
Technology Resources	,335**	,319**	- 0.028	0.078	0.056	0.113	-0.024	,214**
Technology Interaction and Communicati on	0.129	,221**	0.149	,172*	0.031	0.085	-0.035	,350**
TecnTechnolo gy Skills	,208**	0.135	0.040	-0.020	0.109	0.095	-0.046	0.120
Technology Invasion	0.145	,300**	,190*	,160*	0.075	,185*	0.051	,434**
Institutional Technology Support	,168*	,160*	0.076	0.098	0.010	0.049	-0.071	0.067

** . Correlation is significant at the 0.01 level (two-tailed). * . Correlation is significant at the 0.05 level (two-tailed).

In Table 2, the presence of difficult students shows positive correlations with all techno-stressors, particularly with interaction and communication, as well as with institutional techno-support. Academic overload also shows some high correlations with technological overload and techno-invasion. Technology acceptance correlates negatively with techno-skills, as does institutional support with techno-support.

Table 3 shows that depression symptoms correlate with all technostressors except for institutional support, and anxiety also correlates with techno-skills and techno-support.

Table 2 Psychosocial risk factor and techostressors

	Difficult students	Academic Overload	Technologica l Acceptance	Institutiona l Support	Mental load	Resource s
Academic Technology Load	.236**	.473**	-0.128	-0.112	.362**	-0.004
Technology Resources	.361**	0.064	-.176*	-0.063	0.111	-0.077

Technology Interaction and Communication	.511**	.359**	-.209**	-0.042	.372**	0.031
Technology Skills	.348**	.196*	-.547**	-.168*	.181*	-0.058
Technology Invasion	.387**	.456**	-0.094	-0.103	.568**	-0.020
Institutional Technology Support	.426**	.218**	-0.124	-.556**	0.144	-.584**

** . Correlation is significant at the 0.01 level (two-tailed). * . Correlation is significant at the 0.05 level (two-tailed).

Table 3. Dimensions of technostress, effects on mental health

		Depression	Anxiety
Academic Load	Technology	.245**	.170*
Technology Resources		.237**	.173*
Technology Interaction and Communication		.376**	.315**
Technology Skills		.235**	0.135
Technology Invasion		.452**	.364**
Institutional Technology Support		0.145	0.087

** . Correlation is significant at the 0.01 level (two-tailed).

* . Correlation is significant at the 0.05 level (two-tailed).

DISCUSION

From this point of view, we can consider that the results obtained by us show that the working conditions related to the use of technology show a relationship with the technical experts, such as the type of chair and desk used to carry out their activities, particularly with academic technology, techno recursos, and with the perception of techno invasion.

The psychosocial factors associated with techno-strengthening are the presence of difficult students, academic overload, acceptance of technology, and mental load.

It is necessary to point out that difficult students are more closely associated with technical conditions such as communication and interaction (.0.511**) during online classes, which may require new pedagogical forms distinct from classroom activities, for which teachers. The teacher felt ignored and had difficulty verifying the students' learning. The previous factor is related to the fact that many teachers

show little acceptance to the use of technology, and they consider that they do not have the necessary technological skills, as shown in the negative association between technological acceptance and technology due to poor skills or knowledge about the use of the tools.

Mental load, which is a variable studied within cognitive ergonomics, shows itself to be an important factor positively associated with technology interaction and communication (0.372**), and with the perception of technology invasion (0.568**). Furthermore, the appropriate limitations in hours and labor activities inside the home generate an additional cognitive effort to bring your teachers' labor to a good end.

We can also consider that technostressors are associated with mental health effects, particularly depression (0.452**) and anxiety (0.364**) with technoinvasion, which implies few limits within the family relationship.

Building on these findings, and in accordance with the objective, we consider that the results obtained show that working conditions related to technology use are associated with technostressors, such as the type of chair and desk used for work, particularly the academic workload, techno-resources, and the perception of techno-intrusion.

Further, the psychosocial risk factors associated with technostressors are difficult students, academic overload, technology acceptance, and mental workload.

The results are similar to those by García et al. (2022), where technostressors are associated with working conditions, and the greatest health impact was among female teachers.

Ayyagaret et al. (2011) also point out that technostressors are linked to work overload, as are intrusive technological conditions, such as the techno-invasion shown in the results of this study.

The effects on mental health from technology use also coincide with the study by Rey-Merchan and López Arquillo (2021), which found that women show higher levels of anxiety and emotional tension.

CONCLUSIONS

The results highlight the need to implement technology training programs with a gender focus, specifically for female teachers, and to monitor their technological well-being.

Otherwise, their mental health and well-being may be affected. Organizational and ergonomic improvement proposals should be developed to enhance work environments and develop processes.

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DOUBLE SHIFT AND COGNITIVE-PSYCHOSOCIAL FATIGUE IN WORKING STUDENTS OF NORTHEASTERN SONORA: A SOCIOTECHNICAL ERGONOMIC ANALYSIS USING NOM-035 WITH CONCEPTUAL REFERENCE TO NASA-TLX.

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Resumen: En los últimos años se ha observado un fenómeno creciente entre los estudiantes universitarios del noreste del estado de Sonora: la adopción de esquemas simultáneos de estudio y trabajo que configuran lo que puede denominarse un doble turno académico-laboral. Esta condición trasciende la simple ampliación del tiempo dedicado a actividades productivas y formativas. En realidad, constituye una configuración sociotécnica compleja donde convergen demandas cognitivas, exigencias organizativas y dinámicas territoriales propias de una región fronteriza con intensa actividad económica. La interacción de estas dimensiones plantea interrogantes relevantes sobre la sostenibilidad del esfuerzo mental, el bienestar psicológico y el desempeño académico de los estudiantes que sostienen ambas responsabilidades de manera paralela.

El presente estudio examina este fenómeno desde una perspectiva ergonómica sociotécnica, con el propósito de caracterizar las condiciones organizativas y psicosociales que emergen cuando los estudiantes combinan trabajo remunerado con su formación universitaria. El diseño metodológico adoptado fue cuantitativo, transversal y analítico, aplicado a estudiantes del Tecnológico Nacional de México, campus Agua Prieta, que participan simultáneamente en actividades laborales dentro de sectores como el comercio, los servicios y la manufactura ligera. Para la caracterización de los factores psicosociales se utilizó como marco de referencia la Norma Oficial Mexicana NOM-035, la cual permitió identificar dimensiones relevantes relacionadas con la distribución del tiempo, la recuperación física y mental, la intensidad de las demandas laborales y la disponibilidad de recursos organizacionales para afrontarlas. En esta etapa del estudio no se aplicó el instrumento NASA-TLX, sin embargo, su incorporación se propone como una línea

metodológica pertinente para investigaciones futuras orientadas a medición directa de la carga mental.

Los hallazgos preliminares sugieren que la presión temporal y el esfuerzo mental sostenido emergen como dos de los factores más relevantes en percepción de carga de trabajo entre los estudiantes que mantienen este doble compromiso. De manera paralela, se identificaron dificultades asociadas con la recuperación física y cognitiva.

Desde la perspectiva de la ergonomía cognitiva y organizacional, estos resultados permiten interpretar el doble turno estudio-trabajo no únicamente como una coexistencia de dos agendas temporales, sino como sistema de temporalidades superpuestas donde los ritmos académicos, laborales y territoriales interactúan generando presiones continuas sobre los mecanismos de regulación del esfuerzo cognitivo. En este contexto, se configura una posible trayectoria de riesgo caracterizada por fatiga cognitivo-afectiva acumulativa, que a largo plazo podría traducirse en disminución del rendimiento académico, deterioro de la calidad del trabajo y afectaciones al bienestar general.

Más allá de la descripción del fenómeno, esta investigación aporta elementos empíricos para orientar estrategias institucionales de prevención y sostenibilidad cognitiva dirigidas a estudiantes trabajadores. En particular, se subraya la necesidad de explorar modelos de reorganización de la carga académica, así como iniciativas que promuevan condiciones laborales más compatibles con los procesos formativos. Asimismo, el estudio abre la posibilidad de avanzar hacia marcos metodológicos integrados, donde la evaluación psicosocial derivada de la NOM-035 pueda complementarse con instrumentos específicos de medición de carga mental, fortaleciendo así el desarrollo de una ergonomía más sensible a las particularidades sociales, económicas y territoriales del contexto fronterizo.

Palabras clave: Ergonomía, carga mental, factores psicosociales, doble jornada, estudiantes - trabajadores.

Aporte a la ergonomía: El principal aporte de este trabajo a la ergonomía ocupa un doble nivel: conceptual y metodológico.

Desde una perspectiva disciplinaria, esta investigación contribuye al campo de la ergonomía al demostrar que los fenómenos de fatiga cognitiva deben analizarse desde sistemas complejos donde interactúan factores micro, meso y macro organizacionales. La doble jornada no solo implica realizar dos actividades paralelas, sino navegar entre estructuras organizacionales con demandas y temporalidades distintas, lo que exige flexibilidad cognitiva, regulación del esfuerzo y toma de decisiones bajo presión. Al incorporar una lectura sociotécnica, el estudio permite ampliar las bases teóricas existentes y generar marcos interpretativos que explican por qué poblaciones estudiantiles trabajadoras en contextos precarizados presentan patrones diferenciados de sobrecarga cognitiva.

Este trabajo también aporta fundamentos para políticas institucionales enfocadas en la sostenibilidad cognitiva, proponiendo estrategias como reorganización temporal de cargas académicas, flexibilidad horaria, rediseño ergonómico del empleo juvenil y programas preventivos contra fatiga mental. La metodología empleada es replicable y escalable.

Finalmente, esta investigación abre la puerta a nuevas líneas de estudio interdisciplinarias que vinculan ergonomía cognitiva, psicología organizacional, sociología del trabajo y análisis territorial. La identificación de trayectorias de riesgo específicas para regiones precarizadas permite construir instrumentos más sensibles a la variabilidad cultural y económica del país. Asimismo, la metodología favorece comparativos entre regiones, estableciendo patrones nacionales de riesgo cognitivo en estudiantes-

trabajadores. Estas contribuciones fortalecen la articulación disciplinaria entre ergonomía y ciencias sociales, promoviendo la generación de políticas públicas integradas de bienestar académico y laboral orientadas a la sostenibilidad cognitiva, fortaleciendo entendimiento sociotécnico del trabajo estudiantil.

Abstract: In recent years, a growing phenomenon has been observed among university students in the northeastern region of the state of Sonora: the adoption of simultaneous study–work schemes that configure what can be described as a dual academic–labor shift. This condition goes beyond the simple extension of time devoted to productive and educational activities. Rather, it constitutes a complex sociotechnical configuration where cognitive demands, organizational requirements, and territorial dynamics typical of a border region with intense economic activity converge. The interaction of these dimensions raises relevant questions about the sustainability of mental effort, psychological well-being, and academic performance among students who sustain both responsibilities simultaneously.

This study examines this phenomenon from a sociotechnical ergonomic perspective with the purpose of characterizing the organizational and psychosocial conditions that emerge when students combine paid work with university education. The methodological design adopted was quantitative, cross-sectional, and analytical, applied to students from Tecnológico Nacional de México, campus Agua Prieta, who simultaneously participate in work activities in sectors such as commerce, services, and light manufacturing.

For the characterization of psychosocial factors, the Mexican Official Standard NOM-035 was used as a reference framework. This standard allowed the identification of relevant dimensions related to time distribution, physical and mental recovery, the intensity of work demands, and the availability of organizational resources to cope with them. At this stage of the study, the NASA-TLX instrument was not applied; however, its incorporation is proposed as a relevant methodological line for future research aimed at directly measuring mental workload.

Preliminary findings suggest that time pressure and sustained mental effort emerge as two of the most relevant factors in workload perception among students who maintain this dual commitment. At the same time, difficulties associated with physical and cognitive recovery were identified.

From the perspective of cognitive and organizational ergonomics, these results allow the study–work dual shift to be interpreted not merely as the coexistence of two temporal agendas, but as a system of overlapping temporalities in which academic, labor, and territorial rhythms interact, generating continuous pressure on the mechanisms that regulate cognitive effort. In this context, a possible risk trajectory emerges characterized by cumulative cognitive-affective fatigue, which in the long term could translate into decreased academic performance, deterioration in work quality, and impacts on general well-being.

Beyond describing the phenomenon, this research provides empirical elements to guide institutional strategies for prevention and cognitive sustainability aimed at working students. In particular, it highlights the need to explore models for reorganizing academic workloads, as well as initiatives that promote labor conditions more compatible with educational processes. Likewise, the study opens the possibility of advancing toward integrated methodological frameworks where the psychosocial evaluation derived from NOM-035 can be complemented with specific instruments for measuring mental workload, thereby strengthening the development of ergonomics more sensitive to the social, economic, and territorial particularities of border contexts.

Keywords: Ergonomics, mental workload, psychosocial factors, study–work double shift, working students.

Contribution to Ergonomics: The main contribution of this work to ergonomics operates at two levels: conceptual and methodological.

From a disciplinary perspective, this research contributes to the field of ergonomics by demonstrating that cognitive fatigue phenomena must be analyzed within complex systems where micro, meso, and macro organizational factors interact. The dual workload not only implies performing two parallel activities but also navigating between organizational structures with different demands and temporalities, which requires cognitive flexibility, effort regulation, and decision-making under pressure.

By incorporating a sociotechnical perspective, the study expands existing theoretical foundations and generates interpretative frameworks that explain why working student populations in precarious contexts present differentiated patterns of cognitive overload. This work also provides foundations for institutional policies focused on cognitive sustainability, proposing strategies such as temporal reorganization of academic workloads, flexible scheduling, ergonomic redesign of youth employment, and preventive programs against mental fatigue. The methodology used is replicable and scalable.

Finally, this research opens new interdisciplinary lines of study that link cognitive ergonomics, organizational psychology, sociology of work, and territorial analysis. The identification of specific risk trajectories in precarious regions allows the construction of instruments more sensitive to the cultural and economic variability of the country. Likewise, the methodology facilitates comparisons between regions, establishing national patterns of cognitive risk among working students.

These contributions strengthen the disciplinary articulation between ergonomics and social sciences, promoting the development of integrated public policies for academic and labor well-being aimed at cognitive sustainability and a deeper sociotechnical understanding of student labor.

1. INTRODUCTION

In several regions of the northeastern part of the state of Sonora, a silent yet structural transformation can be observed in the contemporary university experience: a growing number of higher education students simultaneously participate in both academic and labor activities, configuring what can be conceptualized as a study-work double shift. This phenomenon should not be interpreted solely as an individual strategy for economic subsistence or for the early accumulation of professional experience. Rather, it should be understood as the outcome of a broader articulation between regional economic dynamics, organizational employment structures, and the particular socio-geographical conditions that characterize border territories. Within these sociotechnical contexts, productive systems converge that are often characterized by high labor turnover, intermittent employment opportunities in sectors such as commerce, services, and light manufacturing, as well as by organizational regimes defined by accelerated work rhythms, strong time pressure, and limited margins of operational autonomy.

The incorporation of students into these productive environments overlaps with the cognitive demands inherent to university education. Higher education learning processes involve sustained requirements for attention, abstract analysis, complex problem solving, and self-regulation of learning. These processes demand a rigorous management of time, mental effort, and individual cognitive resources. When these academic requirements intertwine with work responsibilities that impose intensive productive rhythms and relatively inflexible organizational structures, a scenario emerges in which the individual's psychophysiological regulation capacities may become compromised. In this sense, the study-work double shift does not simply represent the coexistence of two temporal

schedules; instead, it reflects the configuration of a system of concurrent demands that interact across multiple levels of human functioning.

Several studies conducted with university populations have documented that the prolonged accumulation of academic and occupational responsibilities may be associated with manifestations of emotional exhaustion, increased levels of anxiety, and a gradual deterioration of psychological well-being. Recent research indicates that the overlap of cognitive and temporal demands intensifies the emotional vulnerability of working students, generating adverse effects both on academic performance and on psychosocial stability (Senthilkumar et al., 2023). These findings suggest that the phenomenon of the double shift constitutes a potential risk scenario when environmental demands exceed the adaptive capacity of the individual and when the resources available to cope with such pressures become insufficient.

From the perspective of organizational psychology, one of the most influential conceptual frameworks for understanding these processes is the Job Demands–Resources model (JD-R). This model proposes that occupational strain emerges when job demands require sustained expenditure of physical or mental energy without the presence of sufficient organizational resources capable of buffering their impact (Bakker & Demerouti, 2007; Demerouti et al., 2001). The JD-R model has its conceptual origins in the Demand–Control model proposed by Karasek (1979), which argues that work-related stress intensifies particularly when high demands are combined with low levels of control over tasks and limited social support within the organization. Although these frameworks have been widely used to analyze formal work environments, their application to populations simultaneously performing academic and productive roles requires a contextualized analytical approach that takes into account the organizational and territorial specificities shaping the student experience.

In the case of Mexico, the institutional recognition of psychosocial risk factors acquired significant normative relevance with the implementation of Official Mexican Standard NOM-035-STPS-2018, which establishes guidelines for the identification, analysis, and prevention of organizational conditions associated with occupational stress. Among the factors addressed by this regulation are deficient organizational leadership, exposure to excessive workloads, extended working hours, and conflicts between work responsibilities and other domains of everyday life (Cotonieto-Martínez, 2021; Martínez-Mejía et al., 2025). Several empirical studies have demonstrated that prolonged exposure to these conditions is associated with higher levels of psychological strain, reductions in subjective well-being, and deterioration in organizational functioning (Martínez-Mejía et al., 2025). For student populations that actively participate in the labor market while pursuing their academic training, these conditions acquire particular relevance due to the constant interaction between workplace organizational systems and the institutional structures of the academic environment.

From a systemic ergonomic perspective, understanding phenomena such as fatigue, cognitive overload, and psychosocial risk requires moving beyond explanations centered exclusively on the individual. Instead, these processes should be analyzed as components of complex sociotechnical systems in which the organization of work, educational structures, territorial dynamics, and human adaptive capacities interact simultaneously. From this viewpoint, the study–work double shift can be interpreted as an emergent configuration in which mental demands, institutional temporal regimes, and cognitive limitations inherent to human physiology converge (Navarro Bringas et al., 2020). Consequently, analyzing this phenomenon requires an approach that integrates organizational, cognitive, and territorial dimensions within a unified interpretative framework.

Within this context, the present research employs the diagnostic framework established by NOM-035-STPS-2018 to characterize the psychosocial risk conditions

present among students of the Tecnológico Nacional de México, Agua Prieta Campus, who carry out work activities parallel to their academic training. The central objective of this study is to provide empirical evidence that helps explain, in a context-sensitive manner, how psychosocial demands are configured within this population group and how these conditions may influence the sustainability of academic performance and the psychological well-being of working students.

Complementarily, the field of cognitive ergonomics has developed specific instruments designed to estimate perceived mental workload during the performance of complex tasks. Among the most widely recognized is the NASA Task Load Index (NASA-TLX), a tool that allows the evaluation of dimensions such as mental demand, temporal pressure, required effort, experienced frustration, and perceived performance (Hart & Staveland, 1988). While NOM-035-STPS-2018 focuses on identifying organizational factors associated with psychosocial risk, the NASA-TLX provides an approach centered on the subjective cognitive experience associated with task execution. In the present study, this instrument is incorporated solely as a conceptual reference for discussing cognitive workload and was not directly applied to the participants. Nevertheless, its future integration could enrich ergonomic analysis by enabling a more precise measurement of the interaction between cognitive demands, time organization, and the subjective experience of mental effort within working student populations.

2. OBJECTIVES

General Objective: To analyze the relationship between the study–work double shift and psychosocial workload among university students in northeastern Sonora, identifying the distribution of psychosocial risk factors according to employment sector through the diagnostic framework established by NOM-035-STPS-2018.

Specific Objectives:

1. To characterize the socio-labor profile of students who combine academic and work activities in border contexts of northeastern Sonora, considering variables related to employment conditions, time organization, and the total number of hours worked.
2. To identify the prevalence and distribution of psychosocial risk factors among working students participating in the manufacturing, commerce, and services sectors, using the diagnostic dimensions established by NOM-035-STPS-2018.
3. To examine the relationship between employment sector and levels of psychosocial fatigue, through an analysis of covariance (ANCOVA) that allows the evaluation of the effect of the type of labor activity while statistically controlling for the variable of hours worked.

3. METHODOLOGY

The research was conducted under a quantitative approach, with a non-experimental, cross-sectional design and a correlational-analytical scope, conceptually grounded in the principles of sociotechnical ergonomics. This approach made it possible to examine the interaction between organizational working conditions, academic demands, and the socio-labor characteristics of students who combine productive activities with their university education. The study aimed to identify the configuration of psychosocial risk factors associated with the study–work double shift within a border territorial context characterized by dynamic labor markets and heterogeneous organizational structures.

The study population consisted of students from the Tecnológico Nacional de México, Instituto Tecnológico de Agua Prieta campus, who simultaneously engage in academic and work-related activities. From this population, a sample of 413 participants was obtained. These participants provided demographic, academic, and occupational information through a structured questionnaire designed to characterize their insertion into the regional labor market. Data collection allowed the documentation of variables related to age, academic program, type of employment, productive sector, contractual modality, and number of hours worked per week. This set of variables made it possible to construct a descriptive overview of the socio-labor profile of working students, as well as to understand the nature of their participation in the border economic system, where formal and informal employment modalities coexist, work schedules are often variable, and levels of organizational stability differ significantly.

In the first analytical phase, descriptive statistical techniques were applied in order to characterize the socio-labor structure of the sample. Data processing was carried out using SPSS software, version 30, which enabled the calculation of measures of central tendency, dispersion, and frequency distributions for demographic and occupational variables. This analysis made it possible to identify patterns of labor participation among students and to establish the empirical basis for understanding the dual role affiliation—academic and productive—that characterizes this population group in regional contexts marked by high labor mobility.

Subsequently, in order to evaluate the presence of psychosocial risk factors, the Reference Guide established by NOM-035-STPS-2018 was applied. This normative instrument is designed to identify organizational conditions that may affect workers' mental health and overall well-being. The instrument allowed the examination of relevant dimensions such as workload, lack of control over tasks, work-life interference, and other elements associated with the organizational environment. Based on the information obtained, frequency analyses and contingency tables were performed in order to estimate the prevalence of psychosocial risk levels within the studied population.

To deepen the interpretation of the results, the sample was segmented into three major labor sectors representative of the regional labor market: manufacturing or light industry, commerce, and services. This classification made it possible to compare psychosocial conditions associated with different organizational and productive environments. The comparative analysis revealed differentiated patterns in the distribution of psychosocial risk levels, particularly within light manufacturing environments, where higher levels of organizational demands and time pressure were observed more frequently. In a subsequent analytical stage, a covariance analysis model (ANCOVA) was applied using the General Linear Model procedure available in SPSS. The purpose of this analysis was to examine the relationship between the labor sector and the levels of psychosocial workload reported by working students, while statistically controlling for the variable of hours worked. Within the statistical model, the final score of the NOM-035 questionnaire was established as the dependent variable, the labor sector as the independent factor, and the number of hours worked per week as a control covariate. This procedure allowed the estimation of the effect of the type of work environment on perceived psychosocial workload while reducing potential bias derived from differences in exposure time to work activities.

In order to strengthen the statistical interpretation of the results, the Bonferroni adjustment was applied in the multiple comparisons between labor sectors, allowing control of the Type I error associated with multiple contrasts. Additionally, the partial Eta squared statistic (η^2) was calculated as a measure of effect size, providing an estimate of the magnitude of the relationship between the analyzed variables. The inclusion of this indicator made it possible to move beyond interpretations based solely on statistical significance and toward a more substantive evaluation of the ergonomic relevance of the findings.

Finally, from the perspective of cognitive ergonomics, the NASA Task Load Index (NASA-TLX) was considered as a complementary conceptual framework. This instrument is widely used to estimate perceived mental workload during the execution of complex tasks (Hart & Staveland, 1988). However, in the present study the instrument was not directly applied to the sample, and therefore its inclusion is limited to the interpretative and conceptual level. Its reference allows the results to be situated within a broader theoretical framework related to mental workload measurement and opens the possibility for future research integrating more specific cognitive ergonomic measurements within working student populations.

Overall, this methodological strategy made it possible to articulate normative psychosocial evaluation tools with inferential statistical techniques, generating an analytical framework suitable for understanding the relationship between work organization, academic demands, and psychosocial conditions among university students who simultaneously participate in the labor market.

4. RESULTS

The analysis of covariance (ANCOVA) made it possible to examine the relationship between employment sector and the levels of psychosocial risk reported by working students, while statistically controlling for the effect of hours worked. Overall, the adjusted model explained 11.7% of the total variance in the psychosocial risk questionnaire score ($R^2 = .117$; adjusted $R^2 = .069$). Although this percentage indicates a moderate explanatory capacity, it is consistent with the multifactorial nature of psychosocial phenomena in complex sociotechnical contexts, where multiple organizational, cognitive, and territorial dimensions interact simultaneously.

One of the most relevant findings of the model corresponds to the effect of the covariate “hours worked,” which showed a statistically significant influence on levels of fatigue and psychosocial risk. This result indicates that the temporal intensity of the work schedule constitutes a determining factor in the experience of psychosocial strain among working students. The effect size associated with this variable falls within a moderate to moderately high range, suggesting that the amount of time spent working represents a substantive predictor within the analyzed model.

The analysis of the model coefficients allows a more precise interpretation of this relationship. The estimates indicate that each additional hour of weekly work is associated with an approximate increase of 0.87 units in the psychosocial risk score. This pattern suggests a direct relationship between the temporal expansion of the work schedule and the increase in perceived psychosocial workload. From an ergonomic perspective, this finding supports the hypothesis that the accumulation of temporal demands reduces the capacity for cognitive and emotional recovery, particularly among individuals who simultaneously face intensive academic requirements.

In contrast, the employment sector did not show a statistically significant effect on psychosocial risk levels once the number of hours worked was controlled. This suggests that, within the analyzed sample, the specific organizational structure of each productive sector does not independently explain differences in the perception of psychosocial fatigue, at least under the conditions observed in this study. In other words, the results indicate that the strain experienced by working students appears to be more strongly related to the amount of time invested in labor activities than to the sectoral characteristics of the productive environment.

Nevertheless, the analysis of estimated marginal means reveals tendencies that are relevant from an interpretative standpoint. When hours worked are statistically controlled—evaluated at an approximate mean of 41.4 weekly hours—students employed in service and commerce-related activities present the highest average values of psychosocial risk, followed by those working in the industrial or light manufacturing sector. Meanwhile, the group classified under other labor activities presents the lowest average values within the analyzed set.

Although these differences did not reach statistical significance, the observed tendency suggests that certain work environments characterized by high interpersonal interaction, constant time pressure, and organizational variability—as frequently occurs in the service sector—may generate more demanding psychosocial conditions. However, the available evidence indicates that such differences remain subordinate to the more dominant effect of the temporal intensity of the work schedule.

Taken together, the results allow us to affirm that the temporal extension of work emerges as the primary factor associated with psychosocial fatigue among students who maintain a study–work double shift. This finding reinforces the idea that the accumulation of responsibilities across academic and productive contexts generates sustained pressure on mechanisms of cognitive and emotional regulation. From the perspective of sociotechnical ergonomics, the issue does not lie exclusively in the nature of the productive sector itself, but rather in the configuration of temporal regimes that limit opportunities for psychophysiological recovery and balance between academic and work demands.

Table 1. Test of between-subjects effects (ANCOVA)

Dependent variable: Final score						
Source	Type III sum of squares	df	Mean square	F	Sig.	η^2
Corrected model	3851.294 ^a	3	1283.765	2.466	.072	.117
Intercept	2721.546	1	2721.546	5.227	.026	.085
Hours worked	3405.569	1	3405.569	6.541	.013	.105
Grouped sector	860.214	2	430.107	.826	.443	.029
Error	29157.706	56	520.673			
Total	306384.000	60				
Corrected total	33009.000	59				
R squared = .117 (Adjusted R square = .069)						

Table 2. Parameter estimates

Dependent variable: Final score							
Parameter	B	Std. error	t	Sig.	95% confidence interval		η^2
					Lower limit	Upper limit	
Intercept	27.989	14.914	1.877	.066	-1.888	57.866	.059
Hours worked	.874	.342	2.557	.013	.189	1.558	.105
[Grouped sector=1.00]	2.793	6.658	.419	.677	-10.546	16.131	.003
[Grouped sector=2.00]	10.666	8.328	1.281	.206	-6.017	27.349	.028

[Grouped sector =3.00]	0 ^a	.	.	.	.	.	.
<i>This parameter is set to zero because it is redundant.</i>							

Table 3. Estimated marginal means

Estimates				
Dependent Variable: Final Score				
Labor sector (grouped)	Mean	Std. error	95% confidence interval	
			Lower limit	Upper limit
INDUSTRY/MANUFACTURING	66.94 _{9^a}	4.539	57.857	76.041
SERVICES/COMMERCE	74.82 _{3^a}	6.769	61.262	88.383
OTHER	64.15 _{7^a}	4.865	54.411	73.903
Covariates appearing in the model are evaluated at the following values: Hours worked = 41.4000.				

5. DISCUSSION

The results obtained allow for a deeper understanding of the study–work double shift from an ergonomic and organizational perspective. In general terms, the evidence suggests that the psychosocial fatigue experienced by working students cannot be interpreted solely as a mechanical consequence of the lack of available time. Rather, it appears to be the result of a more complex interaction between the temporal intensity of work, task organization, and the structural conditions of the labor environment. The statistical model indicates that hours worked constitute the most consistent predictor of increased psychosocial workload, confirming that the temporal accumulation of productive and academic demands exerts sustained pressure on students' cognitive and emotional regulation mechanisms.

This finding is consistent with the propositions of the Job Demands–Resources (JD-R) model, which argues that strain emerges when demands consume psychophysical resources without the presence of sufficient organizational mechanisms for compensation or support. In the case of working students, labor hours represent a direct form of prolonged exposure to productive demands that overlap with the cognitive requirements of the educational process.

The evidence obtained suggests that this temporal overlap reduces opportunities for psychophysiological recovery and favors the progressive accumulation of fatigue.

However, the results also invite a broader interpretation from the perspective of sociotechnical macroergonomics. Although the employment sector did not show a statistically significant effect once the number of hours worked was controlled, the tendencies observed in the estimated marginal means suggest that certain organizational environments may generate more demanding conditions from a psychosocial standpoint.

In particular, sectors associated with services and commerce presented higher average values of psychosocial risk, which may be linked to labor dynamics characterized by continuous time pressure, constant interaction with users or customers, and lower levels of organizational predictability.

From a territorial perspective, this phenomenon acquires additional nuances in border contexts such as northeastern Sonora. The regional economic structure is strongly influenced by productive systems related to light manufacturing and service activities connected to cross-border commerce. These organizational configurations often operate under conditions of high labor flexibility, personnel turnover, and intensive production rhythms, which may increase time pressure and fragment opportunities for recovery. In this sense, the exhaustion experienced by working students can be interpreted as the result of the interaction between territorial labor market dynamics and the cognitive demands of the educational system, creating a scenario in which the sustainability of mental effort becomes particularly fragile.

Another relevant aspect that emerges from the analysis concerns the measurement instruments used to evaluate psychosocial risks. NOM-035-STPS-2018 represents a robust normative tool for identifying organizational conditions that may affect workers' psychological well-being, particularly in relation to workload, control over tasks, and interference between different spheres of everyday life. However, its methodological structure is primarily oriented toward the identification of organizational risk factors, which creates certain limitations when attempting to directly estimate the subjective experience of mental workload associated with the execution of specific tasks.

In this regard, the incorporation of tools from cognitive ergonomics could significantly enrich the analysis of the study—work double shift. Instruments such as the NASA Task Load Index (NASA-TLX) allow the evaluation of dimensions related to mental demand, temporal pressure, required effort, frustration, and perceived performance during task execution. While NOM-035 enables the identification of organizational conditions associated with psychosocial risk, the NASA-TLX provides an approach centered on the individual cognitive experience. The future integration of both approaches would allow the development of multicomponent methodological strategies capable of capturing both the organizational structure of risk and the perceived mental workload experienced during work activities.

The combination of these tools could provide valuable information for more precisely understanding the mechanisms through which the double shift affects the cognitive sustainability of working students. Furthermore, it would open the possibility of advancing toward more specific ergonomic interventions, aimed at task redesign, the reorganization of work schedules, and the implementation of organizational practices that facilitate the psychophysiological recovery of students.

Finally, it is important to recognize several limitations of the study.

First, the cross-sectional design used prevents the establishment of definitive causal relationships between the analyzed variables, limiting the conclusions to the identification of associations observed within the studied sample. Second, the empirical measurement focused on the evaluation of organizational psychosocial risk factors through NOM-035-STPS-2018, without incorporating a direct measurement of perceived mental workload. Future research could integrate instruments such as the NASA-TLX in order to complement the normative diagnosis with cognitive workload estimates related to dimensions such as mental demand, temporal pressure, effort, and frustration. This integration would strengthen the understanding of fatigue mechanisms among working students and help guide more precise intervention strategies aimed at improving time organization, the management of work demands, and the sustainability of academic performance.

6. CONCLUSIONS

The present research makes it possible to establish that the psychosocial fatigue observed among university students who combine academic and work activities in northeastern Sonora is closely associated with the temporal intensity of the work schedule, rather than with membership in a specific productive sector. The results of the statistical analysis show that the number of hours worked constitutes the factor with the greatest explanatory capacity within the model, demonstrating that the temporal accumulation of productive and academic demands significantly increases the perceived psychosocial workload among working students.

In particular, the estimated model indicates that each additional hour of weekly work is associated with an average increase of 0.87 units in the psychosocial risk score, suggesting the existence of a direct relationship between the expansion of the work schedule and the increase in cognitive and emotional strain. This finding supports the idea that the study-work double shift configures an intensive temporal regime that limits opportunities for psychophysiological recovery and promotes the progressive accumulation of fatigue among students who actively participate in the labor market.

From the perspective of occupational and organizational ergonomics, the results suggest that the prevention of psychosocial risks among working students cannot be reduced solely to interventions focused on the workplace or on the physical dimension of tasks. On the contrary, the evidence points to the need to consider time organization and the distribution of workloads as critical variables in the design of sustainable sociotechnical systems. In this sense, the temporal intensity of work emerges as a structural element that conditions both the psychological well-being and academic performance of students.

Likewise, the findings highlight the usefulness of the diagnostic framework provided by NOM-035-STPS-2018 for identifying organizational conditions associated with psychosocial risk. The application of this instrument made it possible to characterize the labor conditions faced by working students and to demonstrate the relevance of variables such as time pressure and interference between different spheres of daily life. Nevertheless, the analysis also reveals that a comprehensive understanding of the phenomenon requires methodological approaches that integrate both organizational and cognitive dimensions of human effort.

In this context, the evidence generated by the study provides relevant elements for the formulation of institutional strategies aimed at improving the sustainability of academic performance in student populations that maintain active participation in the labor market. In particular, the results suggest the convenience of exploring policies of schedule flexibility, work-study compatibility schemes, and mechanisms for regulating workload, with the aim of reducing the time pressure faced by working students. Collaboration between educational institutions and actors within the productive sector could play a key role in the construction of work environments that are more compatible with educational processes.

Finally, from a methodological perspective, future research could strengthen the diagnosis of risks associated with the study-work double shift by integrating instruments from cognitive ergonomics, such as the NASA Task Load Index (NASA-TLX). The incorporation of this type of tool would allow the organizational evaluation carried out through NOM-035-STPS-2018 to be complemented with direct measurements of perceived mental workload, considering dimensions such as mental demand, temporal pressure, required effort, and task-related frustration. This methodological integration would contribute to a deeper understanding of fatigue mechanisms among working students and would facilitate the design of ergonomic interventions aimed at improving cognitive sustainability in simultaneous educational and labor contexts.

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ERGONOMIC ASSESSMENT OF HYBRID TEACHING WORK: MENTAL WORKLOAD, VISUAL FATIGUE, AND POSTURAL RISK IN A PUBLIC HIGH SCHOOL

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Resumen: El trabajo docente en modalidad híbrida ha incrementado la exposición a pantallas, posturas estáticas y demandas cognitivas. Este estudio transversal evaluó carga mental (NASA-TLX), fatiga visual (CVS-Q) y riesgo postural (RULA/REBA) en 84 docentes de una preparatoria pública universitaria (UMSNH) mediante instrumentos aplicados en línea. La exposición promedio fue 7.4 ± 2.1 h/día. Se observó NASA-TLX total de 63.8 ± 14.7 y mayor carga mental en modalidad virtual/híbrida frente a presencial ($p = 0.011$). La fatiga visual tuvo media 8.9 ± 4.7 con 58.3% de casos; fue mayor en mujeres ($p = 0.038$) y en quienes reportaron >8 h/día ($p < 0.001$). El riesgo postural fue elevado (RULA 5.6 ± 1.3 ; REBA 7.8 ± 2.0), con predominio de niveles alto/muy alto. Se proponen acciones técnicas y organizacionales de bajo costo para facilitar réplicas en instituciones similares.

Palabras clave: ergonomía organizacional; carga mental; fatiga visual; riesgo postural; docencia híbrida.

Relevancia para la ergonomía: El estudio integra ergonomía física, visual y organizacional en un contexto educativo, y entrega un protocolo de evaluación e intervención de bajo costo que puede replicarse para comparar riesgos y priorizar mejoras en instituciones con condiciones similares.

Abstract: Hybrid teaching has increased screen exposure, static postures, and cognitive demands. This cross-sectional study assessed mental workload (NASA-TLX), visual fatigue (CVS-Q), and postural risk (RULA/REBA) among 84

teachers from a public university high school (UMSNH) using online self-administered instruments. Mean screen exposure was 7.4 ± 2.1 h/day. Overall NASA-TLX was 63.8 ± 14.7 and workload was higher in virtual/hybrid than face-to-face teaching ($p = 0.011$). Visual fatigue averaged 8.9 ± 4.7 with 58.3% cases; it was higher in women ($p = 0.038$) and among those reporting >8 h/day ($p < 0.001$). Postural risk was high (RULA 5.6 ± 1.3 ; REBA 7.8 ± 2.0), with a predominance of high/very high levels. Low-cost technical and organizational actions are proposed to enable replication and benchmarking across similar institutions.

Keywords: organizational ergonomics; mental workload; visual fatigue; postural risk; hybrid teaching.

Relevance to Ergonomics: The chapter bridges physical, visual, and organizational ergonomics in educational work and offers a replicable, low-cost assessment and intervention protocol for comparable settings.

1. INTRODUCTION

In recent years, teaching has rapidly incorporated digital tools for course management, communication, and assessment. Hybrid teaching - understood as the combination of face-to-face activities with the systematic support of digital platforms - has become a routine practice in many educational institutions, even outside emergency contexts.

This change has transformed the occupational exposure profile of teachers. Activities that were previously resolved through direct classroom interaction - planning, grading, feedback, and coordination - are now performed more frequently in front of screens, under immediate response demands, and across multiple simultaneous channels, such as email, messaging, institutional platforms, and videoconferencing.

From an occupational ergonomics perspective, this scenario involves at least three axes of risk: (i) physical ergonomics, due to static postures and non-adapted workstations; (ii) visual ergonomics, due to prolonged screen exposure and variable lighting conditions; and (iii) cognitive and organizational ergonomics, due to increased mental workload, time pressure, and multitasking.

In the educational sector, unlike in corporate offices, workstation adjustments are rarely standardized. Hybrid work takes place across classrooms, teachers' rooms, and homes, with heterogeneous furniture, portable equipment, and irregular connectivity. This variability makes risk control and the implementation of uniform measures more difficult.

Evidence on ergonomic risks among teachers has also increased since the expansion of remote work and intensive device use. Recent studies report a high prevalence of musculoskeletal complaints and ocular symptoms in teachers exposed to screens for prolonged periods, particularly when there are no clear practices regarding breaks, workstation ergonomics, and organizational guidelines (Cristancho et al., 2022; Dossari et al., 2022; Ramirez-Garcia et al., 2023).

In this context, comprehensive assessments are needed that measure not only posture, but also mental workload, visual fatigue, and organizational aspects, such as interruptions, time pressure, and ambiguity in digital roles. It is also desirable for protocols to be replicable, low-cost, and comparable across educational institutions in order to build cumulative evidence and guide scalable interventions.

1.1. Conceptual framework: physical, visual, and organizational ergonomics

The approach of this chapter integrates three complementary domains. Physical ergonomics focuses on workstation adequacy and the prevention of musculoskeletal disorders through the analysis of postures, forces, and repetitiveness. For rapid assessments in computer-based work, the RULA method estimates action levels based on the posture of the neck, trunk, and upper limbs (McAtamney & Corlett, 1993).

Visual ergonomics addresses computer vision syndrome, or digital eye strain, which is associated with ocular and visual symptoms related to screen use. The CVS-Q instrument has shown adequate psychometric properties for monitoring symptoms in workers exposed to screens (Segui et al., 2015).

Finally, cognitive and organizational ergonomics considers mental workload and work design, including attention demands, time pressure, effort, and frustration. NASA-TLX is a widely used scale for estimating perceived mental workload in complex tasks (Hart & Staveland, 1988). In hybrid teaching work, these dimensions are related to task multiplicity, channel simultaneity, and the need for rapid responses.

2. OBJECTIVES

2.1. General objective

To comprehensively assess ergonomic risk factors in hybrid teaching work (physical, visual, and mental workload) in a public high school, and to design a low-cost, highly feasible intervention plan for implementation and replication in similar institutions.

2.2. Specific objectives

- To characterize screen exposure, equipment type, and the general conditions of the workstation (classroom, teachers' room, and home).
- To estimate the postural risk associated with computer use through RULA and REBA, and to describe critical tasks.
- To quantify perceived mental workload through NASA-TLX and identify periods or conditions of higher demand.
- To identify visual fatigue symptoms through CVS-Q and associated contextual factors (lighting, breaks, and screen distance).
- To explore, through open-ended questions in the survey, technical and organizational barriers (multitasking, connectivity, and digital guidelines) that modulate exposure.

- To compare mental workload, visual fatigue, and postural risk scores by sex, work modality, and screen time.
- To propose technical and organizational intervention actions, implemented in phases, aimed at enabling protocol replication in similar institutions.

2.3. Scope

The study was limited to teachers from a public university high school (UMSNH) whose teaching activities were supported by computer use. Typical exposures in hybrid teaching were considered, including face-to-face classes with digital support, videoconferences, and the preparation of teaching materials. Results are reported in aggregate form and correspond to the August-September 2025 period; interventions or longitudinal changes were not evaluated.

3. METHODOLOGY

An observational cross-sectional study with a mixed-methods approach (quantitative-qualitative) was conducted. This design was selected to obtain an initial diagnosis of risks using validated instruments and, at the same time, to understand the organizational context that shapes exposure in hybrid teaching work.

The study was conceived as a replicable protocol for educational institutions with limited resources. To this end, rapid, low-cost tools with prior use in occupational ergonomics and visual health were selected.

3.1. Context and participants

The study was conducted in a public high school belonging to Universidad Michoacana de San Nicolas de Hidalgo (UMSNH). The institution operates mainly in face-to-face mode, with digital tools used for planning, material delivery, communication with students, and assessment.

Eighty-four volunteer teachers from different academic areas participated. Inclusion criteria were: (i) teaching during the August-September 2025 period; (ii) using a computer or digital device to support teaching; and (iii) providing informed consent. Incomplete records in the main scales were excluded.

To protect confidentiality, individual information is presented in aggregated form. The sample size corresponds to an exploratory study; larger samples are recommended in replications for inferential analyses and inter-institutional comparisons.

3.2. Assessment instruments

Postural risk (RULA). The Rapid Upper Limb Assessment (RULA) method was applied to estimate the action level required according to the posture of the neck, trunk, and upper limbs during representative digital teaching tasks (McAtamney & Corlett, 1993).

Postural risk (REBA). The Rapid Entire Body Assessment (REBA) method was used to evaluate the risk associated with whole-body postures during computer-based activities and videoconferences, reporting action levels by category.

Mental workload (NASA-TLX). The NASA Task Load Index was applied to estimate perceived mental workload in planning, assessment, and digital communication activities, considering its six dimensions (Hart & Staveland, 1988).

Visual symptoms (CVS-Q). The Computer Vision Syndrome Questionnaire (CVS-Q) was applied to record the frequency and intensity of symptoms associated with screen use (Seguí et al., 2015).

Open-ended questions. Open items were included to document organizational barriers and self-care practices (breaks, lighting, and workstation adjustments) that were relevant for interpreting the findings and guiding improvement actions.

3.3. Procedure

Data collection was carried out online through a self-administered digital questionnaire. In addition to NASA-TLX and CVS-Q, exposure variables (daily screen time, device type, and work modality) were collected, and optional visual evidence (photographs or screenshots) of the participants' usual posture in front of the computer was requested following a brief guide on capture angles and distance.

The visual evidence was used to score RULA and REBA in a standardized manner by a trained evaluator. When sufficient evidence was not available, a guided self-assessment based on postural descriptors was applied, prioritizing consistency for replicability purposes.

Finally, a semi-structured interview was conducted to identify organizational factors (multitasking, time pressure, institutional guidelines, and work-life boundaries) and opportunities for improvement.

3.4. Data analysis

Quantitative data were analyzed using descriptive statistics (frequencies, percentages, and ranges), and exploratory comparisons were performed by workload category (low, medium, and high) to identify trends. Given the sample size, interpretation focused on patterns rather than population-level inference.

Qualitative interview data were analyzed through thematic coding. Recurrent categories related to work organization, technical barriers, break practices, and perceived institutional support were identified. Triangulation allowed postural and visual findings to be linked to organizational triggers.

3.5. Ethical and replicability considerations

The study was conducted with voluntary participation and informed consent, emphasizing confidentiality and the academic use of data. No sensitive information that could identify participants was collected in the final document.

To facilitate replications, the protocol was designed with accessible instruments and a standardized procedure. Institutions interested in replication should keep constant: (i) the measurement period (ideally weeks with comparable academic

workload); (ii) the operational definition of screen time; and (iii) the tasks observed for RULA, so that results are comparable across sites.

An implementation guide, workstation checklist, and prioritization matrix are included in the results and discussion section as transferable tools.

4. RESULTS

Table 1 presents the sociodemographic, work-related, and replicability characteristics of the study sample.

Table 1. Sociodemographic, work-related, and replicability characteristics of the sample.

Variable	Result
Sample	Teachers from a public university high school (UMSNH).
Total N	84
Sex, n (%)	Women: 46 (54.8%); Men: 38 (45.2%).
Age, mean +/- SD (range)	41.7 +/- 9.3 years (25-63).
Teaching seniority, mean +/- SD	13.2 +/- 8.1 years.
Screen time/day, mean +/- SD	7.4 +/- 2.1 h/day.
Modality, n (%)	Face-to-face: 31 (36.9%); Hybrid: 39 (46.4%); Virtual: 14 (16.7%).
Application period	August-September 2025.
Instrument administration	Online, through a self-administered digital questionnaire.
Task assessed for posture	Computer-based teaching, academic videoconferences, and preparation of teaching materials.
Instruments	NASA-TLX, CVS-Q, RULA, and REBA.

Table 2. Results for workload, visual fatigue, postural risk, and between-group comparisons.

Dimension	Indicator	Overall result	Between-group comparisons (p)
Workload	NASA-TLX total (mean +/- SD)	63.8 +/- 14.7	Virtual/Hybrid vs Face-to-face: 68.9 +/- 13.8 vs 57.1 +/- 14.2; p = 0.011
Workload	NASA-TLX subscales (mean +/- SD)	Mental demand 71.2 +/- 16.3; Physical demand 38.6 +/- 18.4; Temporal demand 60.5 +/- 17.1; Performance 66.1 +/- 15.2; Effort 68.7 +/- 16.8; Frustration 49.8 +/- 20.6	-
Visual fatigue	CVS-Q (mean +/- SD) and cases n (%)	8.9 +/- 4.7; 49 (58.3%)	Sex (W vs M): 9.8 +/- 4.5 vs 7.9 +/- 4.6; p = 0.038. >8 h/day vs <=8 h/day: 11.2 +/- 4.3 vs 6.7 +/- 3.8; p < 0.001
Postural risk	RULA (mean +/- SD) and levels n (%)	5.6 +/- 1.3; Low (1-2): 6 (7.1%); Medium (3-4): 24 (28.6%); High (5-6): 41 (48.8%); Very high (7): 13 (15.5%)	Virtual/Hybrid vs Face-to-face: 5.9 +/- 1.2 vs 5.1 +/- 1.1; p = 0.027
Postural risk	REBA (mean +/- SD) and levels n (%)	7.8 +/- 2.0; Low: 11 (13.1%); Medium: 32 (38.1%); High: 30 (35.7%); Very high: 11 (13.1%)	-

4.1. Screen exposure and workstation conditions

Mean screen exposure was 7.4 +/- 2.1 h/day. Distribution by modality was: face-to-face 36.9%, hybrid 46.4%, and virtual 16.7%. The most frequently reported activities included digitally supported teaching, academic videoconferences, preparation of teaching materials, and grading/feedback through platforms.

The predominant use of a laptop without external peripherals was observed mainly at home. This configuration favors sustained neck flexion and shoulder elevation, especially when the screen is below eye level and there is no adequate forearm support.

Lighting conditions were variable. Cases of intense frontal lighting (glare) and insufficient lighting were identified, increasing focusing effort and ocular fatigue, particularly during prolonged reading and review tasks.

4.2. Postural risk (RULA)

The mean RULA score was 5.6 $\pm$ 1.3, corresponding to a level that requires workstation changes. Distribution by level was: Low (1-2) 7.1%; Medium (3-4) 28.6%; High (5-6) 48.8%; Very high (7) 15.5%.

A significantly higher RULA score was observed in teachers working in virtual/hybrid mode compared with face-to-face mode (5.9 $\pm$ 1.2 vs 5.1 $\pm$ 1.1; p = 0.027), suggesting greater exposure to static postures and lower postural variability.

The highest scores were associated with laptop-based setups without peripherals, screens below eye level, and lack of forearm support, especially during prolonged videoconferences and platform-based grading.

4.3. Postural risk (REBA)

The mean REBA score was 7.8 $\pm$ 2.0, placing the sample in a medium-to-high risk range requiring intervention. Distribution by levels was: Low 13.1%; Medium 38.1%; High 35.7%; Very high 13.1%.

The high and very high levels (48.8% combined) reflect sustained trunk and neck flexion, as well as inadequate chair-desk-screen adjustments in mixed environments (classroom and home).

These findings support the need for minimum workstation adjustments (screen height, chair, and peripherals) and organizational practices that encourage active breaks and task alternation.

4.4. Mental workload (NASA-TLX)

Overall mental workload (NASA-TLX) was 63.8 $\pm$ 14.7. The highest subscale score was mental demand (71.2 $\pm$ 16.3), followed by effort (68.7 $\pm$ 16.8) and performance (66.1 $\pm$ 15.2).

Higher NASA-TLX scores were observed in teachers working in virtual/hybrid mode compared with face-to-face mode (68.9 $\pm$ 13.8 vs 57.1 $\pm$ 14.2; p = 0.011), which is consistent with reports of time pressure and multitasking associated with digital channels.

The combination of multiple simultaneous platforms, deadlines, and expectations of rapid response was related to greater temporal demand (60.5 $\pm$ 17.1) and frustration (49.8 $\pm$ 20.6), which are key dimensions for guiding organizational interventions.

4.5. Visual fatigue symptoms (CVS-Q)

The mean visual fatigue score (CVS-Q) was 8.9 $\pm$ 4.7, and 49 cases (58.3%) were identified according to the applied criterion. The most frequently reported symptoms

were ocular burning, intermittent blurred vision, and eye strain at the end of the workday.

Women showed higher visual fatigue scores than men (9.8 ± 4.5 vs 7.9 ± 4.6 ; $p = 0.038$). In addition, those reporting >8 h/day of screen exposure showed greater visual fatigue than those reporting ≤ 8 h/day (11.2 ± 4.3 vs 6.7 ± 3.8 ; $p < 0.001$).

As highly feasible preventive actions, micro-breaks, visual hygiene, and the 20-20-20 rule are recommended, along with adjustments in screen distance/height and lighting to reduce focusing effort.

4.6. Qualitative findings: work organization and barriers

Open-ended responses highlighted four recurrent themes: (i) multitasking and simultaneous channels (messaging, platform, and email); (ii) interruptions due to connectivity problems and equipment failures; (iii) lack of institutional guidelines for digital communication; and (iv) non-standardized workspaces at home.

The absence of shared criteria for digital communication (recommended schedules, official channel, and response times) fosters a dynamic of permanent availability that increases mental workload and reduces opportunities for breaks.

Participants suggested that simple actions - such as scheduling assessment windows, standardizing procedures, and offering brief training in visual and physical ergonomics - could improve work control and reduce cumulative exposure.

4.7. Prioritization matrix and proposed intervention package

Based on the quantitative and qualitative diagnosis (Table 2), a phased intervention package is proposed: (1) minimum workstation adjustment (external peripherals, screen height, and forearm support); (2) individual practices (micro-breaks, task alternation, and visual hygiene); and (3) organizational actions (digital communication guidelines, assessment windows, and periodic follow-up).

5. DISCUSSION AND CONCLUSIONS

The results confirm that hybrid teaching creates a multifactorial ergonomic risk scenario. Prolonged screen exposure and low postural variability, especially in laptop-only workstations without peripherals, are associated with RULA levels that require intervention. This pattern is consistent with reports in teachers and teleworkers during periods of intensive digital work (Cristancho et al., 2022; Nasri et al., 2023).

In the visual domain, the presence of ocular burning and blurred vision is consistent with literature describing the effects of online work on teachers' eye health (Dossari et al., 2022). Lighting conditions and the absence of breaks are highly feasible modifiable factors, so early intervention may yield rapid benefits.

Regarding mental workload, peaks during grading and end-of-term periods suggest that the organizational component is decisive. It is not enough to recommend breaks if the work structure itself encourages permanent availability.

Standardizing digital workflows and defining assessment windows may reduce multitasking and time pressure, with positive effects on well-being and performance.

The proposed package combines technical actions (minimum workstation adjustment), behavioral actions (micro-breaks and postural variability), and organizational actions (guidelines and training). This integration is essential for sustainable interventions and is aligned with recommendations for healthy telework that emphasize ergonomics and organizational support (ILO, 2020; WHO, 2022).

5.1. Limitations

This is a cross-sectional and exploratory study; therefore, it does not establish causality. The sample size limits inferential comparisons and generalization. In addition, screen-time measurement was based on self-report, which may introduce recall bias.

However, the main value of this chapter is to provide a comprehensive diagnosis and a low-cost replicable protocol. Its application in multiple institutions will allow larger samples and more robust comparative analyses.

5.2. Recommendations for future research and replications

To strengthen the evidence base and allow inter-institutional comparisons, the protocol should be replicated in at least three schools with similar profiles (infrastructure, faculty size, and comparable hybrid modality). In each replication, it is advisable to standardize: (i) the measurement period (e.g., weeks 6-8 of the semester and the assessment week); (ii) the definition of 'screen time' (academic digital work excluding leisure); and (iii) the tasks observed for RULA (grading, planning, and videoconferencing).

Longitudinal before-and-after measurements are also recommended after implementation of the intervention package, with quarterly follow-up using brief instruments (CVS-Q, NASA-TLX, and RULA observation). This would make it possible to estimate change and support continuous improvement.

For more detailed analyses, future studies could explore the relationship between mental workload and connectivity quality, as well as evaluate the effect of institutional guidelines on multitasking reduction. It is also advisable to examine differences by academic area, seniority, and teaching load, using larger samples.

5.3. Conclusions

In 84 teachers, hybrid teaching was associated with a relevant ergonomic risk profile: moderate-to-high overall mental workload (NASA-TLX 63.8 +/- 14.7), high prevalence of visual fatigue (58.3%), and elevated postural risk (RULA 5.6 +/- 1.3; REBA 7.8 +/- 2.0), with a predominance of high/very high levels.

Comparisons showed greater mental workload and postural risk in virtual/hybrid teaching than in face-to-face teaching ($p \leq 0.027$), as well as greater visual fatigue in women ($p = 0.038$) and in those reporting >8 h/day of screen exposure ($p < 0.001$). An integrated physical, visual, and organizational ergonomics approach allows

simple and scalable actions to be proposed in order to reduce exposure and improve work control.

5.4. Contributions to ergonomics

This chapter contributes: (i) a replicable online protocol integrating NASA-TLX, CVS-Q, and postural assessment (RULA/REBA) for educational settings; (ii) a quantitative baseline with comparisons by sex, work modality, and screen exposure, useful for inter-institutional benchmarking; and (iii) a set of low-cost technical and organizational recommendations aimed at reducing mental workload, visual fatigue, and postural risk. The proposed standardization facilitates replications in similar institutions and comparison of results in future studies.

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OCCUPATIONAL ERGONOMICS APPLIED TO THE DIGITAL TRANSFORMATION OF ADMINISTRATIVE PROCESSES FOR THE REDUCTION OF WORKLOAD AND THE IMPROVEMENT OF ORGANIZATIONAL WELL-BEING IN A COMMUNITY CENTER

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Resumen: En el Centro Comunitario Palabras de Esperanza se desarrolla un proyecto de transformación digital orientado a la organización y optimización de sus procesos administrativos y de atención. Docentes y estudiantes del Instituto Tecnológico Superior de Puerto Peñasco participan en el diseño y desarrollo de un sistema integral como parte de un esquema de vinculación academia–sector social. El software, actualmente en fase de desarrollo, se estructura de manera modular para atender funciones operativas clave del centro, incluyendo la gestión de citas médicas, quirúrgicas y dentales, la administración de medicamentos de farmacia, la gestión de inventario y préstamo de artículos de ortopedia, el registro de donaciones y el control de pacientes asociados a la elaboración de prótesis. La propuesta tecnológica surge como respuesta a la necesidad de mejorar la organización del trabajo, reducir la carga administrativa y fortalecer el control y seguimiento de la información. Desde un enfoque de ergonomía ocupacional, la digitalización de los procesos se plantea como una intervención orientada a disminuir tareas manuales repetitivas, optimizar la gestión de datos y favorecer la eficiencia operativa. El desarrollo del sistema busca facilitar el seguimiento de los servicios, mejorar la trazabilidad de la información y contribuir al bienestar organizacional del personal involucrado en las actividades administrativas y de atención. El proyecto destaca la transformación digital como una estrategia de intervención ergonómica organizacional en contextos del sector social, así como la importancia de la vinculación académica en la generación de soluciones tecnológicas con impacto operativo y social.

Palabras clave: Ergonomía ocupacional, transformación digital, procesos administrativos, carga de trabajo y bienestar social.

Relevancia para la ergonomía: Este trabajo es relevante para la ergonomía al abordar la transformación digital como una estrategia de intervención ergonómica organizacional. El estudio muestra cómo el diseño e implementación de un sistema digital puede contribuir a la reducción de la carga de trabajo administrativa, la mejora

en la organización de tareas y el fortalecimiento del bienestar organizacional. La importancia de su publicación radica en ampliar el campo de aplicación de la ergonomía hacia contextos administrativos y del sector social, donde este tipo de intervenciones suele estar menos documentado. Asimismo, el capítulo aporta evidencia sobre la integración de principios ergonómicos en procesos de digitalización, destacando su impacto no solo en la eficiencia operativa, sino también en las condiciones del sistema de trabajo.

Abstract: At the Palabras de Esperanza Community Center, a digital transformation project is being developed with the aim of organizing and optimizing its administrative and service processes. Faculty members and students from the Instituto Tecnológico Superior de Puerto Peñasco are involved in the design and development of an integrated system as part of an academia–social sector collaboration framework. The software, currently in the development phase, is structured modularly to address key operational functions of the center, including the management of medical, surgical, and dental appointments, pharmacy medication administration, inventory management and loan control of orthopedic equipment, donation records, and the monitoring of patients associated with prosthesis services. The technological proposal arises in response to the need to improve work organization, reduce administrative workload, and strengthen information control and tracking. From an occupational ergonomics perspective, the digitalization of processes is conceived as an intervention aimed at decreasing repetitive manual tasks, optimizing data management, and enhancing operational efficiency. The system development seeks to facilitate service monitoring, improve information traceability, and contribute to the organizational well-being of personnel involved in administrative and service activities. This project highlights digital transformation as a strategy for organizational ergonomic intervention within social sector contexts, as well as the importance of academic collaboration in generating technological solutions with operational and social impact.

Keywords. Occupational Ergonomics, Digital Transformation, Administrative Processes, Workload, and Social Well-Being.

Relevance to Ergonomics: This work is relevant to ergonomics as it addresses digital transformation as a strategy for organizational ergonomic intervention. The study demonstrates how the design and implementation of a digital system can contribute to the reduction of administrative workload, the improvement of task organization, and the enhancement of organizational well-being. The importance of its publication lies in expanding the field of ergonomics toward administrative and social sector contexts, where such interventions are typically less documented. Furthermore, this chapter provides evidence on the integration of ergonomic principles into digitalization processes, highlighting their impact not only on operational efficiency but also on the conditions of the work system.

1. INTRODUCTION

1.1 Administrative Work in Social Sector Contexts

Administrative work in social sector institutions is often carried out in environments characterized by limited technological resources, high demand for services, and reduced staff. Community centers and non-profit organizations frequently manage appointments, inventories, donations, and service records through manual systems or dispersed digital tools. These conditions can lead to duplication of tasks, fragmented information, and difficulties in operational coordination.

From an ergonomic perspective, administrative work involves a significant cognitive workload associated with information processing, activity coordination, and decision-making. When processes lack structure or adequate technological support, the probability of errors increases and the mental workload of personnel intensifies (Aranguren Álvarez, 2014). In this sense, work organization becomes a key factor influencing both performance and employee well-being.

Ergonomics recognizes that work systems should be designed considering the interaction between people, tasks, tools, and organizational structure (International Organization for Standardization [ISO], 2014). In administrative environments, poor system design can generate unnecessary cognitive effort, process disorganization, and inefficient information flows. From a macroergonomic perspective, organizational factors play a determining role in shaping workload and the overall performance of the work system (Hendrick & Kleiner, 2002).

In the Mexican context, regulatory frameworks such as NOM-036-1-STPS-2018 highlight the importance of identifying and analyzing risk factors associated with work conditions and work organization (Secretaría del Trabajo y Previsión Social [STPS], 2018b). Although this regulation mainly focuses on physical factors, its principles emphasize the need to evaluate how tasks are structured and how they may impact workload.

In social sector institutions, where the priority is community service and resources are often limited, administrative systems frequently evolve without a formal ergonomic evaluation. This situation highlights the importance of analyzing work organization as part of a strategy aimed at improving operational efficiency and organizational well-being.

1.2 Occupational Ergonomics and Workload

Occupational ergonomics focuses on the design and adaptation of work systems in order to optimize human performance and protect people's health and well-being. Beyond physical aspects, the discipline also incorporates cognitive and organizational dimensions, recognizing that the structure of work directly influences workload and the quality of performance (Dul & Weerdmeester, 2008).

In administrative environments, workload is mainly expressed through cognitive demands related to information management, multitasking, and decision-making.

Mental workload theory suggests that when task demands exceed the worker's processing capacity, the likelihood of errors increases and operational efficiency decreases (Wickens, Lee, Liu, & Gordon-Becker, 2004). In fragmented administrative systems, the constant need to switch between records, forms, and different sources of information can generate unnecessary cognitive overload.

From the perspective of sociotechnical systems, organizational performance does not depend solely on the individual, but on the interaction between technology, processes, and organizational structure (Carayon, 2006). When administrative processes lack technological integration or structural clarity, rework, duplication of records, and loss of traceability may occur, affecting both efficiency and employee well-being.

In the Mexican context, the relevance of organizational factors has been recognized in NOM-035-STPS-2018, which establishes the identification and prevention of psychosocial risk factors derived from work organization (Secretaría del Trabajo y Previsión Social [STPS], 2018a). This regulation highlights that the way tasks are distributed, time is managed, and processes are structured can directly affect workload and the organizational environment.

The ergonomic analysis of administrative work therefore requires considering process organization, information flow, and the available technological support. Understanding these elements makes it possible to identify intervention opportunities aimed at reducing unnecessary workload and improving the overall functioning of the work system.

1.3 Digital Transformation as Work System Redesign

Digital transformation in organizations has traditionally been associated with technological modernization and improvements in operational efficiency. However, from an ergonomic perspective, the incorporation of information technologies should not be understood only as a technical change, but as a structural modification of the work system (Baxter & Sommerville, 2011).

The implementation and use of digital tools changes the way tasks are distributed, how information flows are managed, and how activities are coordinated. As a result, digitalization implies a redesign of the sociotechnical system, where people, processes, technology, and organizational structure interact (Carayon & Smith, 2000). If this redesign is not carried out considering ergonomic principles, technology may even increase cognitive workload or generate new forms of operational complexity.

In administrative environments within the social sector, digital transformation can represent an opportunity to reorganize fragmented processes, centralize information, and reduce repetitive manual activities. When designed from a work-centered perspective, technology can function as a support tool that reduces unnecessary workload and improves information traceability (Norman, 2013).

In the Latin American and Mexican context, where many social organizations operate with limited resources and relatively informal administrative structures, digitalization can become a mechanism for strengthening organizational capacity. However, its effectiveness depends on ensuring that technological design responds

to the real characteristics of the work system rather than being driven only by technical criteria.

Digital transformation can therefore be understood as an organizational ergonomic intervention when its objective is to optimize the structure of work, improve task coordination, and contribute to the well-being of personnel. From this perspective, the development of digital systems should be integrated within a broader ergonomic analysis that considers organizational dynamics and the cognitive demands of administrative work.

1.4 Study Context and Rationale

This project is developed at the Palabras de Esperanza Community Center, located in the city of Puerto Peñasco, Sonora, Mexico. The organization's mission is to promote the integral development of families in the community through programs related to education, health, personal development, and spiritual support. Its vision focuses on contributing to the comprehensive transformation of families in the region through community service and support initiatives. See Figure 1.



Figure 1. Front entrance to the community center.

The center offers a variety of programs and services, including:

- Community medical care. See Figure 2
- Surgical and dental consultations
- Medication management and pharmacy services
- Loan of orthopedic equipment
- Support in the development of prosthetic devices
- Educational programs
- Vocational training and activities for children and youth.



Figure 2. Medical care services.

This wide range of services requires continuous and well-coordinated administrative operations, including the management of information, inventory control, appointment scheduling, and the registration and monitoring of beneficiaries. During the initial exploratory visits, it was observed, that several administrative processes were carried out through manual records or non-integrated digital tools. This situation resulted in fragmented information, duplication of tasks, and difficulties in tracking services. In an organization with constant community interaction and multiple active programs, these conditions can directly affect work organization and increase the administrative workload of the staff. See Figure 3.



Figure 3. Administrative processes performed manually

Based on these observations, an inter-institutional collaboration was established with the Instituto Tecnológico Superior de Puerto Peñasco. Through this collaboration, faculty members and students from the Computer Systems Engineering program participate in the development of an integrated digital system for the community center. This initiative represents a collaboration between

academia and the social sector. The intervention goes beyond technological modernization. Its purpose is to redesign the administrative work structure based on principles of occupational ergonomics, optimizing task distribution, improving information flow, and reducing unnecessary workload.

The rationale for this study lies in the need to document how digital transformation can be implemented as a strategy for redesigning work systems in social sector institutions. When organizational analysis is integrated with technological development, it becomes possible to observe the interaction between these elements and the potential benefits that such interventions can generate in underserved contexts. In this way, the project represents an applied ergonomic intervention that contributes both to the operational strengthening of the community center and to the organizational well-being of the personnel involved.

2. OBJECTIVES

2.1 General Objective

To apply principles of occupational ergonomics to the digital redesign of the administrative and service processes of the Palabras de Esperanza Community Center, through the development and implementation of a modular information system, in order to reduce workload and contribute to the improvement of organizational well-being.

2.2 Specific Objectives

- To analyze the administrative work system of the community center, identifying manual processes, task fragmentation, and factors associated with workload.
- To design and develop a modular digital system with an ergonomic approach that integrates medical, surgical, and dental appointment management, pharmacy control, inventory and loan management of orthopedic equipment, donation records, and prosthesis monitoring.
- To implement the system as a support tool for administrative work, aimed at improving task organization, operational efficiency, and information traceability.
- To evaluate the effects of the digital intervention on work organization and on the perceived workload of the community center personnel.

3. METHODOLOGY

3.1 Study Design

This study was conducted under an applied research approach aimed at addressing a real problem identified at the Palabras de Esperanza Community Center. Applied research seeks to generate useful knowledge for solving concrete situations in specific contexts by integrating theoretical analysis with practical action (Hernández Sampieri, Fernández Collado, & Baptista, 2014).

The project was structured as a case study, since it involved an in-depth analysis of a specific organizational system with the objective of directly intervening in its administrative functioning. Case studies allow the understanding of contemporary phenomena within their real-life context, especially when the boundaries between the phenomenon and the context are not clearly defined (Yin, 2018).

Methodologically, the study was defined as non-experimental and descriptive, but with direct intervention. It is considered non-experimental because variables were not manipulated under controlled conditions. Instead, the existing work system was examined to identify opportunities for improvement from an occupational ergonomics perspective. Based on this analysis, a technological intervention was designed and implemented as a strategy for organizational redesign. As shown in Figure 4.

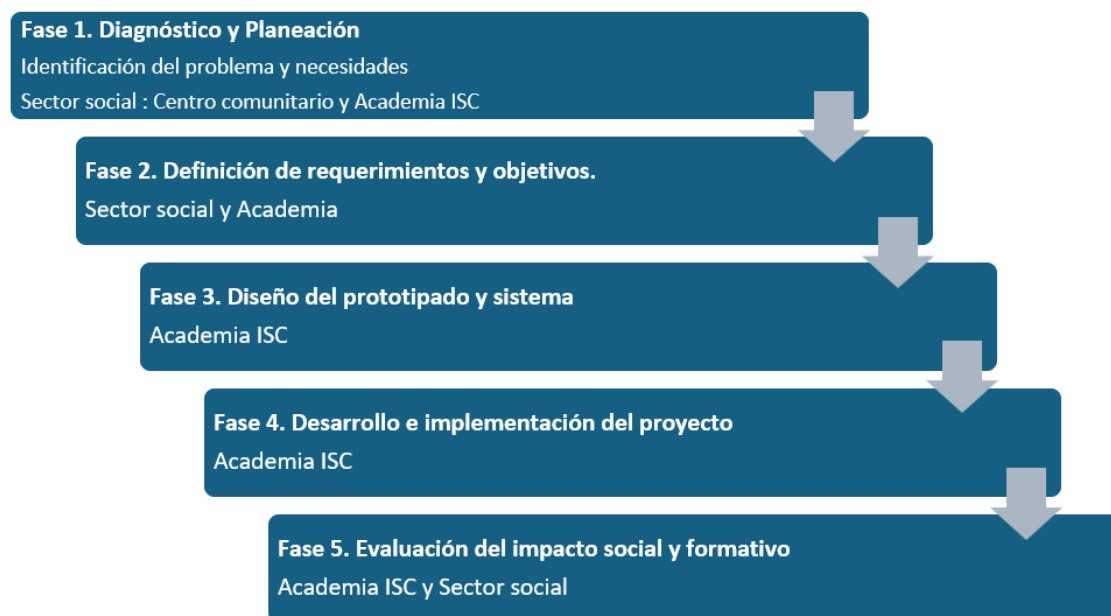


Figure 4. Methodology applied to the project

The adopted approach integrates principles of organizational analysis and sociotechnical systems, considering the interaction between people, tasks, and technological tools. In this sense, the development of the digital system was not limited to the programming of a software application, but was conceived as an

intervention aimed at optimizing the work structure and reducing administrative workload.

Furthermore, the project was developed within a collaboration framework between academia and the social sector, with the participation of faculty members and students from the Instituto Tecnológico Superior de Puerto Peñasco, reinforcing both its applied nature and its social impact.

3.2 Organizational Context

From an organizational perspective, the community center integrates several functional areas that interact constantly: reception and appointment management, pharmacy services, control of medical equipment inventory, donation records, and monitoring of beneficiaries. These areas share critical information for daily operations, creating an interdependent administrative dynamic.

Activities take place in different physical spaces — including consultation rooms, the pharmacy area, the reception desk, and storage areas — which require continuous coordination to ensure the efficient delivery of services. See Figure 5 and Figure 6.



Figure 5. Areas of focus Community Center



Figure 6. Consultation rooms

Prior to the intervention, administrative processes were mainly carried out through manual records and non-integrated digital tools. This situation resulted in the use of multiple information formats and fragmented data management. Although functional, this structure required a significant administrative effort to coordinate appointments, control inventory, and track services. Additionally, if the center were to expand its services or activities, these difficulties could increase. As shown in Figure 7 and Figure 8.

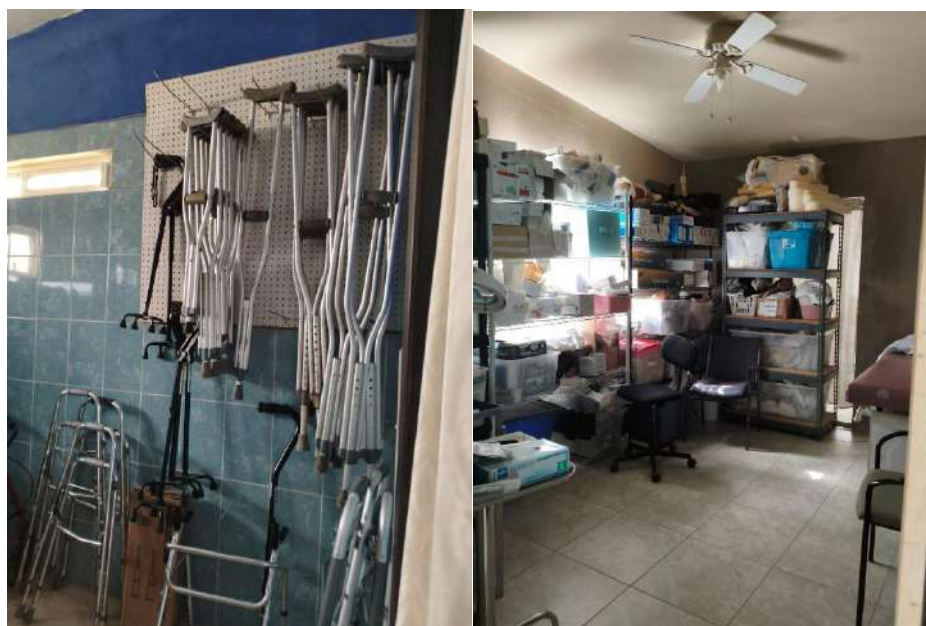


Figure 7. Medical equipment storage area

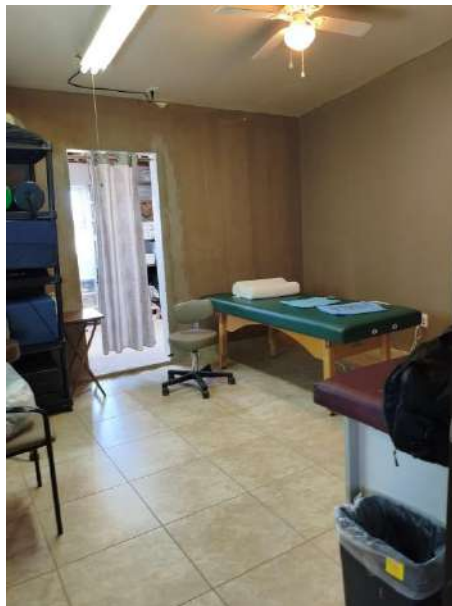


Figure 8. Physiotherapy treatment area.

3.3 Work System Analysis

The analysis of the work system was carried out in order to understand the organizational structure and administrative processes of the community center, identifying operational dynamics, information flows, and potential sources of workload.

Several qualitative and descriptive techniques were used for data collection. First, direct observation of administrative processes was conducted to document activities related to appointment management, pharmacy control, inventory of orthopedic equipment, donation records, and the monitoring of patients associated with prosthesis services. This observation made it possible to identify the sequence of tasks, interaction points between areas, and the tools used in daily operations.

In addition, semi-structured interviews were conducted with administrative and operational staff to understand how activities were performed, the difficulties perceived in managing information, and the main challenges related to work organization. These interviews provided insight into administrative workload from the direct experience of the system users.

The analysis also included the review of documents, formats, and records used in daily operations, as well as the mapping of information flows between the different areas. This stage made it possible to detect duplicated records, fragmented data management, and the absence of integrated technological support. See Figure 9.



Figure 9. Workflow analysis of different areas

3.4 Identification of Ergonomic Issues

Based on the analysis of the work system, several situations were identified that could be addressed from the perspective of occupational ergonomics, particularly in the organizational domain.

One of the main findings was the disorganization and fragmentation of administrative information, resulting from the use of manual records and non-integrated digital tools such as spreadsheet files. This situation generated duplicated tasks, the constant need for cross-checking information, and a higher probability of errors in the management of appointments, inventory, and medical services.

Administrative overload associated with repetitive tasks was also identified. Activities such as manually transcribing data, updating records in multiple formats, and searching for historical information required additional effort that did not directly contribute to service delivery but increased the time spent on operational work.

Another relevant issue was the lack of structured traceability in several processes, particularly in inventory control, prosthesis follow-up, and donation records. Without an integrated system, accessing information quickly and making decisions based on historical data became more difficult. See Figure 10.



Figure 10. Repetitive patient record entries

From the perspective of organizational ergonomics, these conditions represent factors that influence workload, system efficiency, and employee well-being. In this case, the structure of the administrative system — rather than the complexity of individual tasks — was identified as the main source of additional effort.

3.5 Ergonomic Intervention Strategy

The intervention strategy was designed based on the findings of the work system analysis and focused on the organizational redesign of administrative processes through technological integration. The proposal was not limited to developing a software tool but was conceived as an ergonomic intervention aimed at optimizing work structure and reducing unnecessary administrative workload.

The approach was based on principles of organizational ergonomics and user-centered design, prioritizing task simplification, information integration, and the reduction of repetitive activities. The intervention criteria included data centralization, standardization of records, and improvements in process traceability.

For the system development, an iterative methodology based on progressive prototyping was used. Initially, functional models representing the identified workflows were designed and validated through feedback sessions with community center staff. This process made it possible to adjust the system structure to real operational needs, avoiding unnecessary functions or additional complexity.

The intervention was organized into functional modules, each corresponding to a specific operational area, such as appointment management, pharmacy control, inventory and loan of orthopedic equipment, donation records, and prosthesis monitoring. This modular structure allowed the identified problems to be addressed gradually, facilitating staff adaptation and reducing the disruptive effects of technological change. See Figure 11.

From an ergonomic perspective, the strategy aimed to:

- Reduce information fragmentation
- Decrease cognitive workload related to searching and verifying information

- Minimize repetitive administrative tasks
- Improve coordination between areas through an integrated system

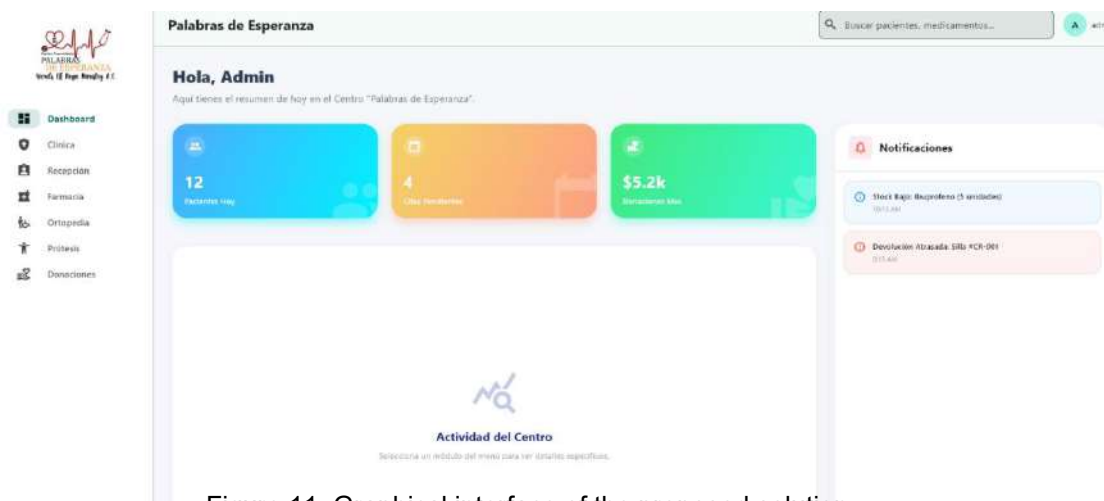


Figure 11. Graphical interface of the proposed solution

In this way, the digital system was designed as a support tool for administrative work, intended to strengthen the functioning of the organizational system and contribute to the well-being of personnel involved in administrative management.

4. RESULTS

The implementation of the digital system currently under development allowed the identification of relevant improvements in the organization of administrative work at the Palabras de Esperanza Community Center. Although the project is still in a progressive implementation phase, the preliminary results show changes in information management, task coordination, and the reduction of repetitive administrative activities. See Figure 12.

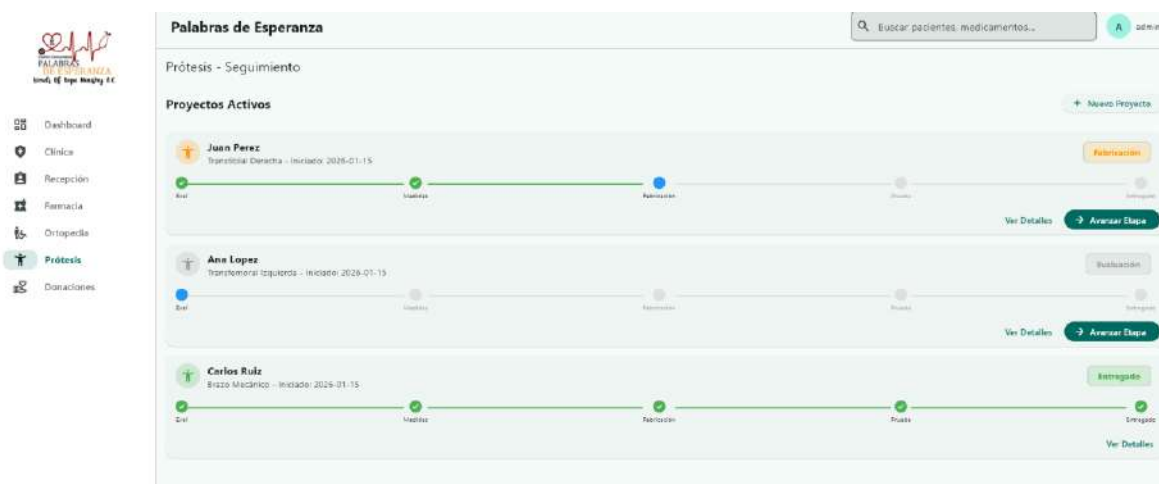


Figure 12. First stage of the proposed solution

4.1 Work Organization Improvements

One of the main results observed was an improvement in the organization of administrative processes within the community center. The integration of different functions into a digital system made it possible to structure activities more clearly, which were previously carried out through manual records or dispersed tools.

The digitalization of processes such as medical appointment management, pharmacy control, donation records, and the monitoring of patients associated with prosthesis services helped establish more defined procedures and reduce duplicated records. Likewise, the modular structure of the system allowed related tasks to be grouped within the same working environment, facilitating coordination between the different operational areas.

These improvements contributed to greater clarity in workflow and in the distribution of administrative activities within the community center.

4.2 Effects on Administrative Workload

Another relevant result was the reduction of repetitive administrative activities. Before the intervention, many tasks involved transcribing information into different records or performing manual searches to locate historical data.

With the integration of information into a centralized system, staff can access the necessary data more quickly for service delivery, reducing the time spent searching and verifying information. This contributes to decreasing the administrative workload associated with operational tasks that do not directly add value to service delivery. See Figure 13.



Figure 13. Multidisciplinary collaborative work

In this way, the system functions as a support tool for administrative work, allowing personnel to dedicate more time to activities related to the management and delivery of community services.

4.3 Information Flow and Traceability

The implementation of the digital system also improved the flow of information within the organization. The centralization of records makes it possible to maintain updated information about medical appointments, medication inventory, orthopedic equipment, donations, and prosthesis monitoring.

This integration facilitates information consultation and improves service traceability, since data are stored and organized within a single system. The ability to access structured historical records contributes to better administrative control and clearer monitoring of operational processes. Improved information traceability represents an important advancement for the operational management of the community center.

4.4 Operational System Benefits

Overall, the digital system provides operational benefits that contribute to strengthening the administrative management of the community center. Among the main benefits identified are improved process organization, more efficient access to information, and the reduction of redundant administrative tasks.

In addition, the modular structure of the system allows its functions to be expanded progressively as new operational needs are identified. This characteristic facilitates the adaptation of the system to the growth of the community center's activities.

Taken together, these results show that the digitalization of administrative processes can function as a support tool to improve work organization and strengthen the operational capacity of institutions within the social sector.

5. DISCUSSION

The results obtained in this study show that the digitalization of administrative processes can represent a relevant intervention from the perspective of organizational ergonomics. Beyond the incorporation of technological tools, the implementation of the system made it possible to reorganize the way tasks, information, and coordination between operational areas are managed at the Palabras de Esperanza Community Center.

One of the most relevant aspects observed was the improvement in the organization of administrative work. The integration of processes that were previously fragmented allowed the establishment of a more structured information flow, reducing duplicated records and facilitating access to relevant data for the center's operations. These improvements are consistent with studies on sociotechnical systems, which emphasize that the interaction between technology, processes, and organizational structures directly influences the performance of work systems (Carayon, 2006).

Similarly, the reduction of repetitive administrative tasks suggests a potential decrease in the cognitive workload associated with manual information management. In administrative environments where multiple records must be handled and data frequently verified, the lack of technological integration can increase the mental demands placed on workers (Wickens et al., 2004). The centralization of information within a digital system helps simplify these activities and facilitates task execution.

Another important element identified is the improvement in information traceability. In community organizations that provide multiple services simultaneously, the ability to consult historical records and monitor administrative processes is a key factor for operational efficiency. In this sense, digitalization not only improves data management but also strengthens the organizational capacity to coordinate services and support decision-making.

From the perspective of occupational ergonomics, these results highlight the importance of analyzing the structure of the work system when introducing technological solutions. When digitalization is approached as a process of organizational redesign rather than simply as technological implementation, it can help reduce unnecessary workload, improve coordination between tasks, and strengthen employee well-being.

Finally, the modular approach adopted in the development of the system represents an appropriate strategy for organizational contexts with limited resources, which is common in institutions within the social sector. The possibility of implementing the system progressively allows the technology to adapt to the real needs of the organization, facilitating its adoption by users and reducing the disruptive effects often associated with abrupt technological changes.

Overall, these findings suggest that digital transformation, when designed under ergonomic principles, can function as an effective tool to improve the organization of administrative work and strengthen the functioning of community-based institutions.

6. CONCLUSIONS

This study analyzed the implementation of a digital transformation strategy aimed at redesigning the administrative processes of the Palabras de Esperanza Community Center from the perspective of occupational ergonomics. Through the analysis of the work system and the identification of issues related to fragmented information, duplicated tasks, and administrative workload, it was possible to design a technological intervention focused on improving work organization.

The results show that integrating administrative processes through a digital system contributes to structuring activities more clearly, facilitating access to information, and reducing repetitive tasks. These improvements help optimize workflow and support staff in managing the different services offered by the community center.

From an ergonomic perspective, the study shows that the digitalization of processes can function as an organizational intervention when it is aimed at simplifying tasks, improving information traceability, and strengthening coordination between operational areas. In this sense, technology is not limited to automating existing activities but also makes it possible to rethink the way administrative work is organized.

Likewise, the modular nature of the system facilitates its progressive implementation and its adaptation to the real needs of the organization. This characteristic is particularly relevant in institutions within the social sector, where resources are often limited.

Finally, the project demonstrates the potential of collaboration between academic institutions and community organizations to develop technological solutions with organizational and social impact. Initiatives of this type contribute not only to improving the operational efficiency of institutions but also to strengthening the organizational well-being of the personnel involved in providing services to the community.

7. CONTRIBUTION TO ERGONOMICS

This study contributes to the field of occupational ergonomics by addressing the digital transformation of administrative processes as a form of organizational ergonomic intervention. Traditionally, ergonomic interventions have been mainly associated with the physical adaptation of workplaces or with the prevention of biomechanical risks. However, contemporary ergonomics recognizes the importance of analyzing work systems from an organizational and sociotechnical perspective, where task structure, information flows, and interaction with technological tools directly influence workload and human performance.

In this context, the study provides evidence of how the redesign of administrative processes through digital systems can contribute to improving work organization. The intervention developed in the community center shows that the digitalization of administrative tasks can reduce information fragmentation, simplify repetitive activities, and facilitate coordination between operational areas. These

elements have a direct impact on employees' cognitive workload and on the efficiency of the work system, which are key aspects of organizational ergonomics. Another important contribution of the project is the adoption of a modular approach in the design of the system. This approach allows technological improvements to be implemented progressively and adapted to the needs of the organizational environment. From an ergonomic perspective, this strategy supports the gradual adaptation of users to technological change, reduces operational complexity, and facilitates the appropriation of the system by the personnel. This type of approach is particularly relevant in organizations within the social sector, where technological and administrative resources are often limited.

Furthermore, the study contributes to expanding the application of ergonomics to administrative and community environments, which have been less documented compared to industrial contexts. The experience developed at the Palabras de Esperanza Community Center demonstrates that ergonomic principles can be effectively applied to analyze and improve administrative processes related to community health services and social support programs.

The project also highlights the importance of integrating ergonomics into digital transformation processes within social organizations. The participation of an academic institution in the development of the system made it possible to incorporate principles of work analysis and user-centered design, strengthening the interdisciplinary nature of the intervention. In this way, the study illustrates the potential of ergonomics to contribute to the design of technological solutions aimed at improving both organizational performance and the well-being of the people involved in work systems.

Overall, these contributions show that ergonomics can play an important role in the digital transformation of organizations in the social sector by providing conceptual and methodological frameworks that support the design of work systems that are more efficient, better organized, and centered on people.

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PHYSICAL CONDITION AND FATIGUE ASSESSMENT OF A CUSTOMER SERVICE EMPLOYEE IN A LOCAL STORE

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Resumen: En el ámbito de la ergonomía y la salud ocupacional, la evaluación de la fatiga forma parte de una práctica para conservar el bienestar de los trabajadores y prevenir trastornos asociados a la sobrecarga física y mental, a su vez ayuda a prevenir riesgos de accidentes y mantener niveles óptimos de productividad y de calidad de vida. Por ello, para su medición pueden emplearse diversas metodologías, pero en este trabajo se utilizarán el cuestionario de Yoshitake, 4 puntos de Luke, el mapeo de Corlett y Bishop, y el SOFI. Además, de manera complementaria se estarán evaluando las condiciones físicas a las que está expuesto el trabajador, todo esto bajo las condiciones que decretan las Normas Oficiales Mexicanas.

La integración de estos métodos de evaluación subjetiva con el marco normativo mexicano permite no solo determinar la presencia de fatiga y cansancio en la trabajadora, sino también identificar con precisión las dimensiones específicas afectadas (fatiga física, mental, emocional, de concentración, visual o de falta de motivación) y los posibles orígenes de dichas alteraciones.

Dicha aproximación multidimensional resulta particularmente valiosa, dado que las condiciones ambientales (ruido, temperatura, iluminación, ventilación y vibraciones) guardan una estrecha relación con el desempeño laboral y el estado de salud de los trabajadores. El cumplimiento de los límites y condiciones establecidos en las normas referidas es indispensable para garantizar entornos de trabajo óptimos.

Esta combinación de herramientas subjetivas y objetivas facilita, por tanto, un diagnóstico más completo y fundamentado, orientado a la implementación de medidas preventivas y correctivas específicas que promuevan entornos laborales saludables y eficientes.

Con base a los resultados obtenidos de las evaluaciones de las condiciones físicas, de acuerdo con las NOM'S, se concluye que el establecimiento evaluado cumple con casi todas, excepto con la NOM-025-STPS-2008 (iluminación), debido a que el lugar está ubicado en una zona donde entra mucha luz solar y al anochecer no cuenta con los límites mínimos de luz.

Durante tres semanas de evaluación se identificó que la trabajadora presenta fatiga moderada tanto física como mental. El cuestionario de Yoshitake mostró síntomas de somnolencia, monotonía, dificultades de concentración y malestar corporal, mientras que el método de los 4 puntos de Luke indicó niveles de cansancio entre “cansada” y “muy cansada”, aumentando al final de la jornada y en días con mayor carga laboral.

Por su parte, el método SOFI evidenció falta de energía y discomfort físico, que se intensifican a lo largo del día. El mapeo de Corlett y Bishop identificó molestias principalmente en cabeza, cuello, espalda, hombros, piernas y pies. En conjunto, los resultados sugieren que la fatiga se relaciona con la carga física del trabajo y la organización laboral, por lo que se recomienda implementar pausas activas, mejorar la organización de tareas y promover estrategias para reducir el estrés.

Palabras clave: Condiciones físicas, fatiga, métodos de evaluación

Relevancia para la ergonomía: Con base en los resultados del estudio, se evidencia la importancia de realizar una evaluación integral de la fatiga laboral, considerando factores físicos y mentales. Se identificó que las condiciones ambientales inadecuadas, las posturas incorrectas y la alta demanda laboral incrementan los niveles de fatiga y afectan el desempeño del trabajador. En este sentido, se recomienda el rediseño de las estaciones de trabajo y la implementación de medidas ergonómicas como tapetes antifatiga, con el propósito de generar un ambiente seguro para el trabajador, para reducir riesgos, lesiones o accidentes y poder mantener un buen servicio al cliente, cuidando al trabajador.

Abstract: In the field of ergonomics and occupational health, fatigue assessment is a practice aimed at preserving worker well-being and preventing disorders associated with physical and mental overload. It also helps prevent accidents and maintain optimal levels of productivity and quality of life. Therefore, various methodologies can be used to measure fatigue, but this study will utilize the Yoshitake questionnaire, the Luke 4-point scale, the Corlett and Bishop mapping, and the SOFI (Socially Induced Fatigue) scale. Additionally, the physical conditions to which the worker is exposed will be evaluated, all in accordance with the Mexican Official Standards.

The integration of these subjective assessment methods with the Mexican regulatory framework allows not only the determination of the presence of fatigue and tiredness in the worker, but also the precise identification of the specific dimensions affected (physical, mental, emotional, concentration, visual, or motivational fatigue) and the possible origins of these issues.

This multidimensional approach is particularly valuable, given that environmental conditions (noise, temperature, lighting, ventilation, and vibrations) are closely related to work performance and the health of employees. Compliance with the limits and conditions established in the relevant standards is essential to guarantee optimal working environments.

This combination of subjective and objective tools thus facilitates a more comprehensive and well-founded diagnosis, geared towards the implementation of specific preventive and corrective measures that promote healthy and efficient work environments.

Based on the results obtained from the physical condition assessments, in accordance with the NOMs (Mexican Official Standards), it is concluded that the evaluated establishment complies with almost all of them, except for NOM-025-STPS-2008 (lighting), because the location is in an area with abundant sunlight and does not meet the minimum light limits at nightfall.

During three weeks of evaluation, it was identified that the worker presents moderate physical and mental fatigue. The Yoshitake questionnaire showed symptoms of drowsiness, monotony, difficulty concentrating, and bodily discomfort, while Luke's 4-point method indicated levels of fatigue between "tired" and "very tired," increasing at the end of the workday and on days with a heavier workload.

For its part, the SOFI method revealed a lack of energy and physical discomfort, which intensify throughout the day. The Corlett and Bishop mapping identified discomfort primarily in the head, neck, back, shoulders, legs, and feet. Overall, the results suggest that fatigue is related to the physical workload and work organization, so it is recommended to implement active breaks, improve task organization and promote strategies to reduce stress.

Keywords. Physical conditions, fatigue, assessment methods.

Relevance to Ergonomics: Based on the study's findings, the importance of conducting a comprehensive assessment of workplace fatigue, considering both physical and mental factors, is evident. It was identified that inadequate environmental conditions, incorrect postures, and high work demands increase fatigue levels and negatively impact worker performance. Therefore, the redesign of workstations and the implementation of ergonomic measures, such as anti-fatigue mats, are recommended to create a safe environment for workers, reduce risks, injuries, and accidents, and maintain excellent customer service while protecting employee well-being.

1. INTRODUCTION

In the field of ergonomics and occupational health, fatigue assessment is a key practice for maintaining worker well-being and preventing disorders associated with physical and mental overload. According to the Royal Spanish Academy (n.d.), fatigue is "discomfort caused by prolonged or prolonged effort or other causes, which sometimes produces physical alterations." Therefore, various methodologies can be used to measure fatigue, but this study will utilize the Yoshitake questionnaire, the Luke 4-point scale, the Corlett and Bishop body part mapping, and the SOFI (Swedish Occupational Fatigue Inventory).

In addition, the physical conditions to which the worker is exposed will be evaluated, all in accordance with the Mexican Official Standards (NOM). These

standards include NOM-011-STPS-2001 (noise), NOM-015-STPS-2001 (thermal conditions), NOM-025-STPS-2008 (lighting), NOM-016-STPS-1993 (ventilation), and NOM-024-STPS-2001 (vibrations).

The worker being evaluated primarily works as a cashier in a department store, Monday through Saturday, from 3:00 p.m. to 8:00 p.m. She also performs duties such as customer service, inventory counting, and cleaning and organizing merchandise.

The objective of this evaluation is to assess and propose improvements to the worker's physical working conditions, as well as to suggest potential improvements.

2. OBJECTIVES

2.1 General

Determine the physical conditions, fatigue levels, and potential for bodily harm experienced by the worker while performing their tasks at their workstation, in order to identify possible risks and opportunities for ergonomic improvement.

2.2 Specific

- Identify the tasks and duties performed by the worker during their workday.
- Apply the Yoshitake ergonomic assessment method, the Luke, Corlett & Bishop 4-point method, and the SOFI method to analyze their posture and physical workload.
- Evaluate the physical conditions, fatigue levels, and potential for bodily harm of the worker's work environment using NOM-011-STPS-2001, NOM-015-STPS-2001, NOM-025-STPS-2008, NOM-016-STPS-1993, and NOM-024-STPS-2001 standards.
- Conduct sampling and direct observations of the worker in their various positions or activities.
- Identify areas for improvement and propose ergonomic recommendations that contribute to reducing risk and improving worker performance.

3. METHODOLOGY

To carry out the methods, visits were made for 3 weeks to the premises where the employee works and the respective interviews were carried out for data collection, likewise the evaluations of the environmental conditions were also carried out at different points of the establishment and different times of the day such as the entrance, shelves and checkout.

3.1 Physical Conditions Assessment

3.1.1 Lighting

The work area to be assessed has a high ceiling with several lamps, both warm and cool (mostly warm) to create a balanced overall light tone. Additionally, the premises receive ample sunlight. Most of the lights are located in the center of the premises, with additional lights near the checkout area. There are no lights at the entrance.

Table 1. Level of illumination with sunlight

ILLUMINATION LEVEL (LUX) BY WORKSTATION				
Measuring point	Location	Lighting level found	Minimum lighting level NOM-025-STPS-2008	It complies with the standard
1	Door (entrance)	469	200	Yes
2	Shelves with merchandise	353	200	Yes
3	Cash registrer	270	300	No

According to the table above, the values shown were measured using an application called “Lux Light Meter Pro” and the resulting illumination levels were compared with the specifications of NOM-025-STPS-2008 (Official Gazette of the Federation, 2008). The minimum illumination level for the entrance and merchandise shelves is 200 lux, as specified in the standard for personnel services, such as customer service, and because it requires simple visual visibility for inventory counting. For the checkout area, a minimum of 300 lux was used due to the work area being a packaging area (primarily for gifts) and requiring moderate detail recognition.

The evaluated work area does not fully comply with the regulations, as the checkout area does not meet the minimum adequate illumination level. It is recommended to install more lights to provide a safe and healthy work environment for the proper performance of the tasks carried out by the employees.

Evidence:

Entrance



Figure 1. Evidence of lighting at entrance with sunlight

Shelves with merchandise

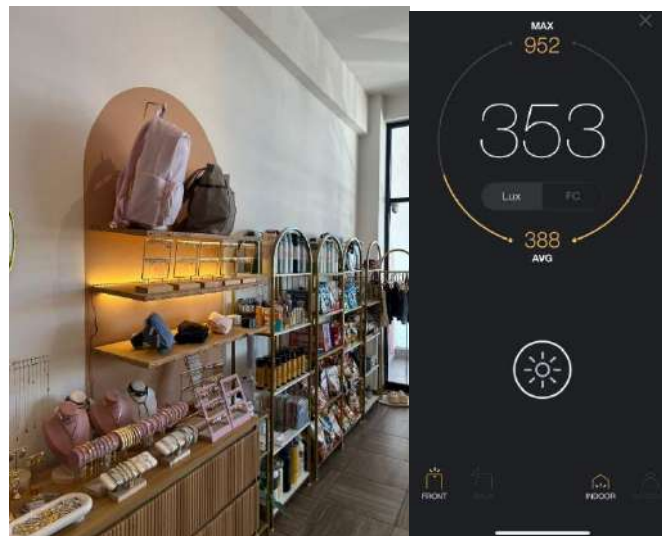


Figure 2. Evidence of lighting on shelving with sunlight

Cash registrar

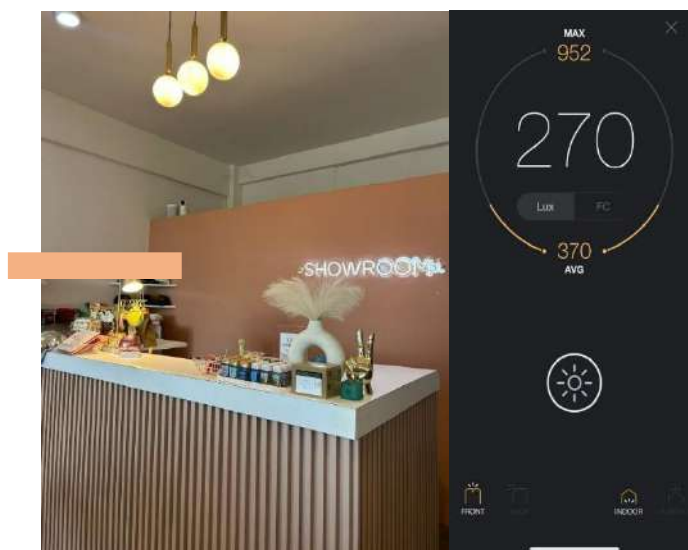


Figure 3. Evidence of lighting in the Cash register area with sunlight

Table 2. Illumination level without sunlight

ILLUMINATION LEVEL (LUX) BY WORKSTATION				
Measuring point	Location	Lighting level found	Minimum lighting level NOM-025-STPS-2008	It complies with the standard
1	Door (entrance)	22	200	No
2	Shelves with merchandise	44	200	No
3	Cash register	79	300	No

According to NOM-025-STPS-2008 (Official Gazette of the Federation, 2008), none of the locations meet the minimum lighting level, which could cause various health problems for workers, such as eye strain, headaches and migraines, and postural problems from trying to see screens, among other issues. It is recommended to install more lights, preferably with a better balance of warm and cool colors.

Evidence:
Entrance

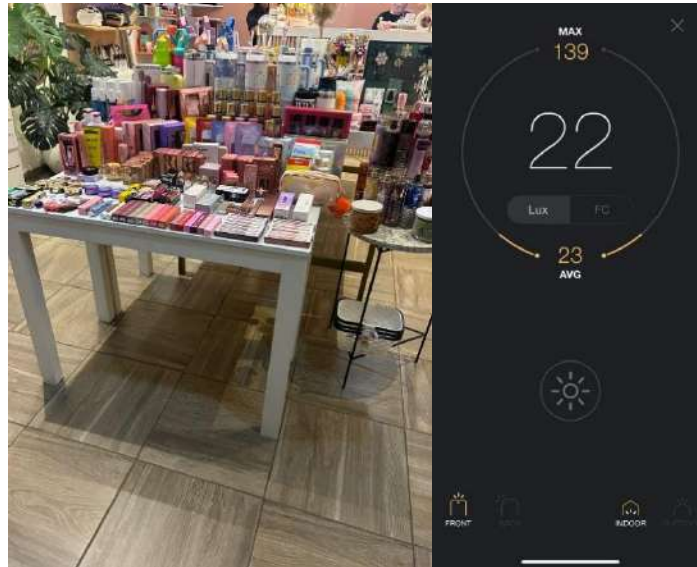


Figure 4. Illumination level found at entrance without sunlight

Shelves with merchandise



Figure 5. Illumination level found on a shelf without sunlight

Cash registrar

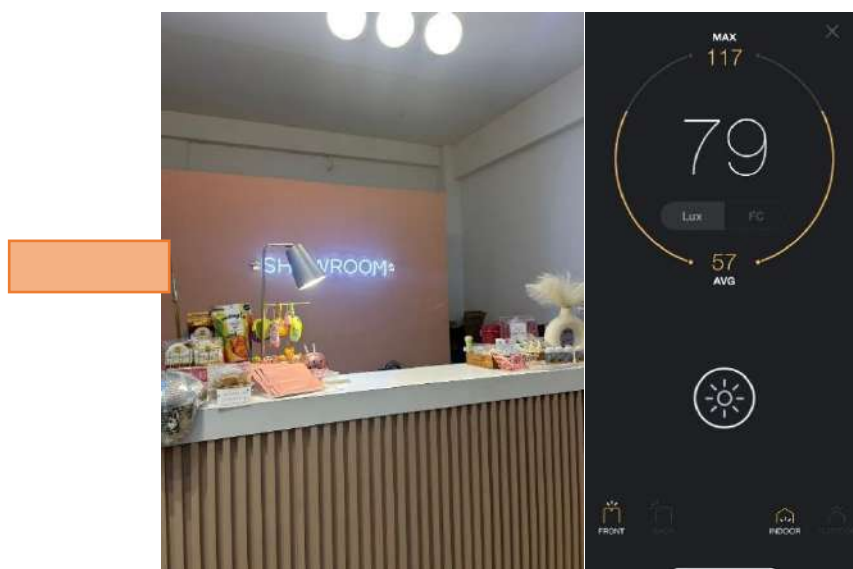


Figure 6. Illumination level found in the Cash registrer area without sunlight

3.1.2 Temperature

The work area being evaluated has air conditioning that is on all day at a moderate temperature, neither too cold nor too hot, maintaining a constant temperature of approximately 23°C to 24°C.

To evaluate and analyze whether the establishment is within the maximum temperature limits, the “Romm Temperature + Thermometer” application was used and compared with NOM-015-STPS-2001 (Official Gazette of the Federation, 2001). The maximum limits used were up to 30°C, since the work being evaluated is light-duty and the exposure can be 100%.

Table 3. Temperature level results

TEMPERATURE LEVEL BY WORKSTATION				
Measuring point	Location	Temperature level found	Maximum temperature limit NOM-015-STPS-2001	It complies with the standard
1	Door (entrance)	25.4°C	30°C	Yes
2	Shelves with merchandise	25.4°C	30°C	Yes
3	Cash registrer	25.4°C	30°C	Yes

After analyzing the results in the table above, it can be observed that the establishment does comply with the temperature established by the standard in the light work category, it is considered light because the worker performs activities such as standing, walking sometimes a little, or if sitting, there are moderate movements of the arm and trunk (answering messages) in a 5-hour workday.

Evidence:

Entrance, shelves with merchandise and cash registrer



Figure 7. Evidence of the temperature level at the entrance, shelves with merchandise and cash registrer

3.1.3 Noise

The work area being evaluated is almost always noisy, due to a speaker constantly playing music and the noise generated by customers.

Table 4. Noise level results

NOISE LEVEL dB(A) BY WORKSTATION				
Measuring point	Location	Noise level found	Maximum noise limit NOM-011-STPS-2001	It complies with the standard
1	Door (entrance)	55.2 dB(A)	90-93 dB(A)	Yes

2	Shelves with merchandise	57.8 dB(A)	90-93 dB(A)	Yes
3	Cash registrer	52.8 dB(A)	90-93 dB(A)	Yes

According to the table above, the noise levels obtained using an application called "Sound Level Meter" were compared with the specifications of NOM-011-STPS-2001 (Official Gazette of the Federation, 2001), where the maximum noise limits were considered based on working hours. A workday of up to 8 hours has a maximum limit of 90 dB(A). Since the work being evaluated is a 5-hour shift, it falls within this maximum noise limit to which the worker may be exposed.

The evaluated work area does comply with the maximum limits established in the standard because it is below the decibel levels established for the workday.

Evidence:

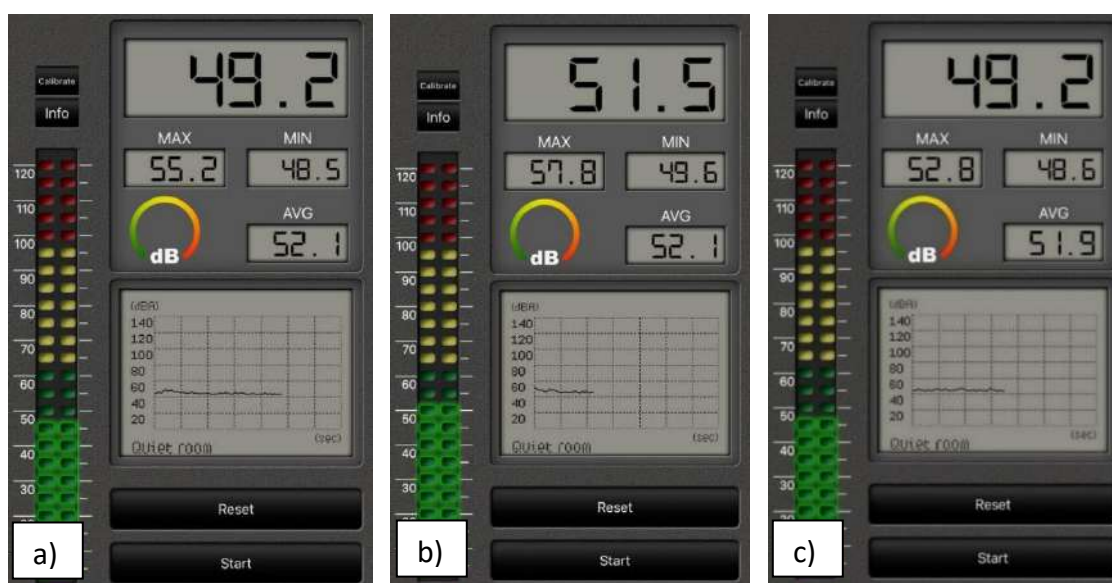


Figure 8. Noise level at a) Entrance, b) Merchandise shelves, c) Cash registrer

3.1.4 Vibration

Within the facility, vibration was almost nonexistent, with intervals of 0.01–0.08 m/s², as no vibration of any kind was found that could affect the work environment or the workers, making it a safe and suitable place to work.

To evaluate and analyze whether the facility is within the maximum vibration limits, NOM-024-STPS-1993 (Official Gazette of the Federation, 1993) and an application called "Earthquake Detector Vibrometer" were used. The maximum permissible dominant acceleration values are up to 4 m/s² with a total daily exposure time of 4 to 8 hours.

Table 5. Vibration level results

VIBRATION LEVEL (m/s ²) BY WORKSTATION				
Measuring point	Location	Vibration level found	Maximum vibration limit NOM-024-STPS-1993	It complies with the standard
1	Door (entrance)	0.08 m/s ²	4 m/s ²	Yes
2	Shelves with merchandise	0.04 m/s ²	4 m/s ²	Yes
3	Cash registrer	0.01 m/s ²	4 m/s ²	Yes

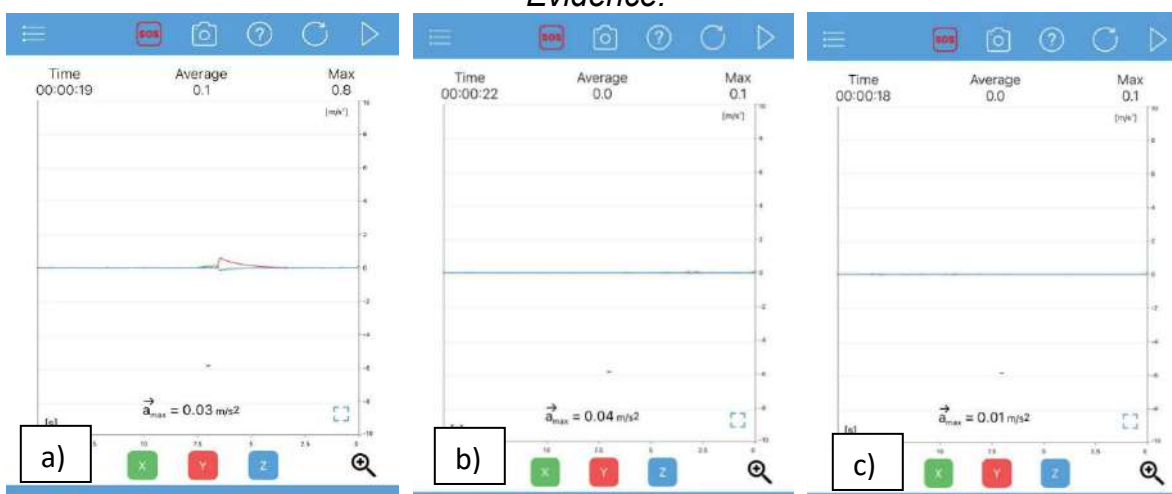
Evidence:

Figure 9. Vibration level at a) Entrance, b) Shelving with merchandise, c) Cash registrer

3.1.5 Ventilation

Regarding ventilation, the premises do not have a ventilation system, only air conditioning. NOM-016-STPS-1993 (Official Gazette of the Federation, 1993) aims to establish the necessary ventilation through natural or artificial systems to help prevent harm to workers' health.

Therefore, the evaluated premises do have artificial ventilation due to the air conditioning.



Figure 10. Evidence of ventilation

3.2 Fatigue Assessment

3.2.1 Yoshitake Questionnaire

The Yoshitake Questionnaire was used to assess the level of mental and physical fatigue in the worker over a 3-week period. This method consists of a questionnaire with 30 closed-ended (yes/no) questions about physical, mental, and behavioral symptoms.

FORMATO DE CUESTIONARIO DE YOSHITAKE

NOMBRE: MELANY IBARRA GARCIA

MODULO Cajera en SHOWROOM

1. LISTA DE VERIFICACIÓN DE SINTOMAS SUBJETIVOS DE FATIGA

Conteste Si o No a las siguientes preguntas

A. SINTOMAS DE SOMNOLENCIA Y MONOTONIA		B. SINTOMAS DE DIFICULTAD DE CONCENTRACIÓN		C. SINTOMAS CORPORALES O PROTECCION DE DAÑOS	
1. Siente pesadez en su cabeza		1. Tiene algunas dificultades para pensar cuando realiza sus tareas		1. Tiene dolor de cabeza	
L M M J V S		L M M J V S		L M M J V S	
Entrada S N S N S N S N S N		Entrada S N S N S N S N S N		Entrada S N S N S N S N S N	
Salida S N S N S N S N S N		Salida S N S N S N S N S N		Salida S N S N S N S N S N	
2. Tiene cansancio en todo su cuerpo		2. No tiene ganas de hablar debido a que el trabajo lo agobia		2. Siente tensión en los hombros	
L M M J V S		L M M J V S		L M M J V S	
Entrada S N S N S N S N S N		Entrada S N S N S N S N S N		Entrada S N S N S N S N S N	
Salida S N S N S N S N S N		Salida S N S N S N S N S N		Salida S N S N S N S N S N	
3. Tiene cansancio en las piernas o las siente pesadas		3. La tarea que usted realiza, llega a ponerlo nervioso o estresado		3. Siente dolor en la espalda	
L M M J V S		L M M J V S		L M M J V S	
Entrada S N S N S N S N S N		Entrada S N S N S N S N S N		Entrada S N S N S N S N S N	
Salida S N S N S N S N S N		Salida S N S N S N S N S N		Salida S N S N S N S N S N	
4. Durante este tiempo ha estado bostezando (a partir del inicio de su trabajo o desde la última pesada)		4. Siente incapacidad de concentrarse y poner atención durante su trabajo		4. Se siente agobiado al respirar	
L M M J V S		L M M J V S		L M M J V S	
Entrada S N S N S N S N S N		Entrada S N S N S N S N S N		Entrada S N S N S N S N S N	
Salida S N S N S N S N S N		Salida S N S N S N S N S N		Salida S N S N S N S N S N	
5. Siente algún malestar en el cerebro (es decir abotado o que sus ideas se embarullan)		5. Ha perdido el interés en las cosas de su trabajo		5. Tiene sed	
L M M J V S		L M M J V S		L M M J V S	
Entrada S N S N S N S N S N		Entrada S N S N S N S N S N		Entrada S N S N S N S N S N	
Salida S N S N S N S N S N		Salida S N S N S N S N S N		Salida S N S N S N S N S N	
6. Usted tiene sueño		6. Se le olvidan las cosas relacionadas con su trabajo		6. Se le ha enrojecido la voz	
L M M J V S		L M M J V S		L M M J V S	
Entrada S N S N S N S N S N		Entrada S N S N S N S N S N		Entrada S N S N S N S N S N	
Salida S N S N S N S N S N		Salida S N S N S N S N S N		Salida S N S N S N S N S N	
7. Siente cansancio en sus ojos		7. Tiene fallos de confianza en sí mismo, de tal manera que cometa errores en su trabajo con más frecuencia de lo normal		7. Se siente mareado o aturdido	
L M M J V S		L M M J V S		L M M J V S	
Entrada S N S N S N S N S N		Entrada S N S N S N S N S N		Entrada S N S N S N S N S N	
Salida S N S N S N S N S N		Salida S N S N S N S N S N		Salida S N S N S N S N S N	
8. Se le dificulta hacer algún movimiento (se siente torpe o adormecido)		8. Se siente ansioso o inquieto al momento de realizar sus tareas		8. Se siente deslumbrado o con excesivo parpadeo de ojos	
L M M J V S		L M M J V S		L M M J V S	
Entrada S N S N S N S N S N		Entrada S N S N S N S N S N		Entrada S N S N S N S N S N	
Salida S N S N S N S N S N		Salida S N S N S N S N S N		Salida S N S N S N S N S N	
9. Siente inseguridad al estar de pie (porque se siente adormecido)		9. Tiene dificultad para enderezar su postura después de que ha realizado su tarea		9. Tiene temblor en los brazos o piernas	
L M M J V S		L M M J V S		L M M J V S	
Entrada S N S N S N S N S N		Entrada S N S N S N S N S N		Entrada S N S N S N S N S N	
Salida S N S N S N S N S N		Salida S N S N S N S N S N		Salida S N S N S N S N S N	
10. Siente ganas de estrarse		10. Siente que le falta paciencia para hacer las cosas de su trabajo		10. Se siente mal o enfermo (malestar general)	
L M M J V S		L M M J V S		L M M J V S	
Entrada S N S N S N S N S N		Entrada S N S N S N S N S N		Entrada S N S N S N S N S N	
Salida S N S N S N S N S N		Salida S N S N S N S N S N		Salida S N S N S N S N S N	

Figure 11. First week of evaluation

The colors in the following tables represent the level of fatigue experienced by the evaluated worker. Purple indicates a low level of fatigue, with a range of 0 to 23.33; yellow corresponds to a moderate level of fatigue, with a range of 23.34 to 43.33; and finally, red represents an excessive level of fatigue, with a range of 43.34 to 100.

Table 6. Percentages of entries and exits week 1

	FQF-E	FQF-S
L	23.33	33.33
M	36.66	53.33
M	43.33	40
J	50	50
V	26.66	46.66
S	36.66	43.33

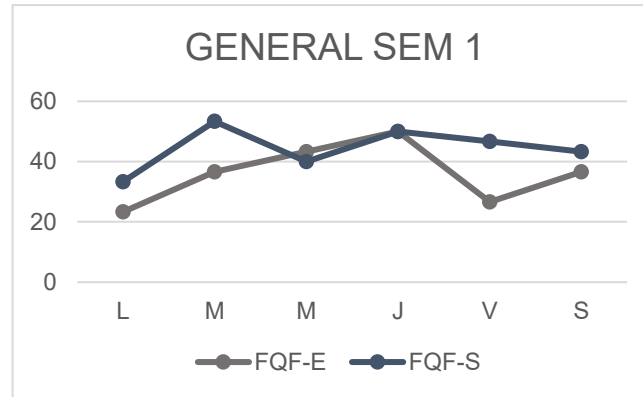


Figure 12. General graph week 1

The overall graph for the first week reflects that the worker is mostly in moderate fatigue, where on Tuesday at the end of the day she presents excessive fatigue.

FORMATO DE CUESTIONARIO DE YOSHITAKE

NOMBRE: MELANY IBARRA
MODULO: CAJERA EN SHOWROOM

LISTA DE VERIFICACIÓN DE SÍNTOMAS SUBJETIVOS DE FATIGA

Conteste Si o No a las siguientes preguntas:

A. SÍNTOMAS DE SOMNOLENCIA Y MONOTONÍA		B. SÍNTOMAS DE DIFICULTAD DE CONCENTRACIÓN		C. SÍNTOMAS CORPORALES O PROYECCIÓN DE DAÑOS	
1. Siente pesadez en su cabeza		1. Tiene algunas dificultades para pensar cuando realiza sus tareas		1. Tiene dolor de cabeza	
Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N
Salida	S N S N S N S N S N	Salida	S N S N S N S N S N	Salida	S N S N S N S N S N
2. Tiene cansancio en todo su cuerpo		2. No tiene ganas de hablar debido a que el trabajo lo agobia		2. Siente tensión en los hombros	
Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N
Salida	S N S N S N S N S N	Salida	S N S N S N S N S N	Salida	S N S N S N S N S N
3. Tiene cansancio en las piernas o las siente pesadas		3. La tarea que usted realiza, llega a ponerlo nervioso o estresado		3. Siente dolor en la espalda	
Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N
Salida	S N S N S N S N S N	Salida	S N S N S N S N S N	Salida	S N S N S N S N S N
4. Durante este tiempo ha estado bostezando (a partir del inicio de su trabajo o desde la última medición)		4. Siente incapacidad de concentrarse y poner atención durante su trabajo		4. Se siente agobiado al respirar	
Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N
Salida	S N S N S N S N S N	Salida	S N S N S N S N S N	Salida	S N S N S N S N S N
5. Siente algún malestar en el cerebro (es decir, abotagado o que sus ideas se embarullan)		5. Ha perdido el interés en las cosas de su trabajo		5. Tiene sed	
Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N
Salida	S N S N S N S N S N	Salida	S N S N S N S N S N	Salida	S N S N S N S N S N
6. Usted tiene sueño		6. Se le olvidan las cosas relacionadas con su trabajo		6. Se le ha enronquecido la voz	
Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N
Salida	S N S N S N S N S N	Salida	S N S N S N S N S N	Salida	S N S N S N S N S N
7. Siente cansancio en sus ojos		7. Tiene fallas de confianza en sí mismo, de tal manera que cometa errores en su trabajo con más frecuencia de la normal		7. Se siente mareado o aturdido	
Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N
Salida	S N S N S N S N S N	Salida	S N S N S N S N S N	Salida	S N S N S N S N S N
8. Se le dificulta hacer algún movimiento (se siente torpe o adormecido)		8. Se siente ansioso o inquieto al momento de realizar sus tareas		8. Se siente deslumbrado o con excesivo parpadear de ojos	
Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N
Salida	S N S N S N S N S N	Salida	S N S N S N S N S N	Salida	S N S N S N S N S N
9. Siente inseguridad al estar de pie (porque se siente adormecido)		9. Tiene dificultad para enderezar su postura después de que ha realizado su tarea		9. Tiene temblor en los brazos o piernas	
Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N
Salida	S N S N S N S N S N	Salida	S N S N S N S N S N	Salida	S N S N S N S N S N
10. Siente ganas de estrarse		10. Siente que le falta paciencia para hacer las cosas de su trabajo		10. Se siente mal o enfermo (malestar general)	
Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N	Entrada	S N S N S N S N S N
Salida	S N S N S N S N S N	Salida	S N S N S N S N S N	Salida	S N S N S N S N S N

Figure 13. Second week of evaluation

Table 7. Percentages of entries and exits, week 2

	FQF-E	FQF-S
L	0	0
M	43.33	46.66
M	46.66	40
J	26.66	40
V	23.33	30
S	36.66	36.66

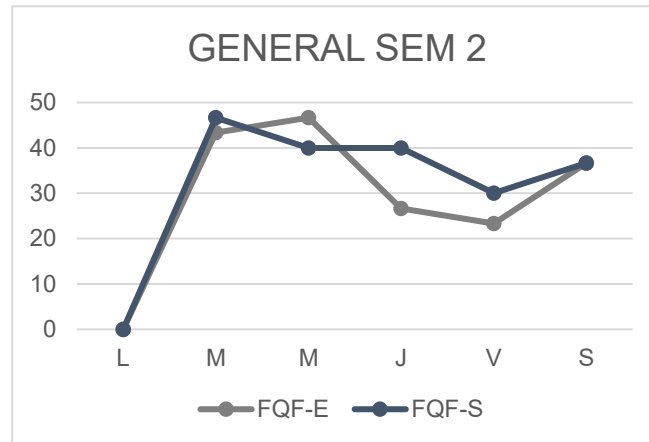


Figure 14. General graph week 2

This graph presents the general data for the second week, covering the three symptom sections. The worker is mostly in moderate fatigue, but on Tuesday and Wednesday there is excessive fatigue, which may be due to the workload she had during those two days, and from Thursday to Saturday that workload decreased.

FORMATO DE CUESTIONARIO DE YOSHITAKE

NOMBRE: MELVY IBARRA
MODULO: CAJERA EN SHOWROOM

1. LISTA DE VERIFICACIÓN DE SÍNTOMAS SUBJETIVOS DE FATIGA

Contraste: Si o No a las siguientes preguntas

A. SÍNTOMAS DE SOMNOLENCIA Y MONITONIA		B. SÍNTOMAS DE DIFICULTAD DE CONCENTRACIÓN		C. SÍNTOMAS CORPORALES O PROYECCIÓN DE DAÑOS	
1. Siente pesadez en su cabeza		1. Tiene algunas dificultades para pensar cuando realiza sus tareas		1. Tiene dolor de cabeza	
L M M J V S		L M M J V S		L M M J V S	
Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N	
Salida: S N S N S N S N S N		Salida: S N S N S N S N S N		Salida: S N S N S N S N S N	
2. Tiene cansancio en todo su cuerpo		2. No tiene ganas de hablar debido a que el trabajo lo agota		2. Siente tensión en los hombros	
L M M J V S		L M M J V S		L M M J V S	
Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N	
Salida: S N S N S N S N S N		Salida: S N S N S N S N S N		Salida: S N S N S N S N S N	
3. Tiene cansancio en las piernas o las siente pesadas		3. La tarea que usted realiza, llega a ponerlo nervioso o estresado		3. Siente dolor en la espalda	
L M M J V S		L M M J V S		L M M J V S	
Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N	
Salida: S N S N S N S N S N		Salida: S N S N S N S N S N		Salida: S N S N S N S N S N	
4. Durante este tiempo ha estado bofeando (a parte del inicio de su trabajo o desde la última merienda)		4. Siente incapacidad de concentrarse y poner atención durante su trabajo		4. Se siente agotado al respirar	
L M M J V S		L M M J V S		L M M J V S	
Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N	
Salida: S N S N S N S N S N		Salida: S N S N S N S N S N		Salida: S N S N S N S N S N	
5. Siente algún malestar en el cerebro (es decir, abogado o que sus ideas se emborran)		5. Ha perdido el interés en las cosas de su trabajo		5. Tiene sed	
L M M J V S		L M M J V S		L M M J V S	
Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N	
Salida: S N S N S N S N S N		Salida: S N S N S N S N S N		Salida: S N S N S N S N S N	
6. Usted tiene sueño		6. Se le olvidan las cosas relacionadas con su trabajo		6. Se le ha enrojecido la voz	
L M M J V S		L M M J V S		L M M J V S	
Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N	
Salida: S N S N S N S N S N		Salida: S N S N S N S N S N		Salida: S N S N S N S N S N	
7. Siente cansancio en sus ojos		7. Tiene fallas de confianza en sí mismo, de tal manera que comete errores en su trabajo con más frecuencia de lo normal		7. Se siente mareado o aturrido	
L M M J V S		L M M J V S		L M M J V S	
Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N	
Salida: S N S N S N S N S N		Salida: S N S N S N S N S N		Salida: S N S N S N S N S N	
8. Se le dificulta hacer algún movimiento (se siente torpe o adormecido)		8. Se siente ansioso o inquieto al momento de realizar sus tareas		8. Se siente deslumbrado o con excesivo parpadeo de ojos	
L M M J V S		L M M J V S		L M M J V S	
Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N	
Salida: S N S N S N S N S N		Salida: S N S N S N S N S N		Salida: S N S N S N S N S N	
9. Siente inseguridad al estar de pie (porque se siente torpe o adormecido)		9. Tiene dificultad para enderezar su postura después de que ha realizado su tarea		9. Tiene temblor en los brazos o piernas	
L M M J V S		L M M J V S		L M M J V S	
Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N	
Salida: S N S N S N S N S N		Salida: S N S N S N S N S N		Salida: S N S N S N S N S N	
10. Siente ganas de estirarse		10. Siente que le falta paciencia para hacer las cosas de su trabajo		10. Se siente mal o enfermo (malestar general)	
L M M J V S		L M M J V S		L M M J V S	
Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N		Entrada: S N S N S N S N S N	
Salida: S N S N S N S N S N		Salida: S N S N S N S N S N		Salida: S N S N S N S N S N	

Figura 15. Third week of evaluation

Table 8. Percentages of entries and exits, week 3

	FQF-E	FQF-S
L	33.33	40
M	23.33	26.66
M	30	20
J	36.66	30
V	13.33	10
S	36.66	26.66

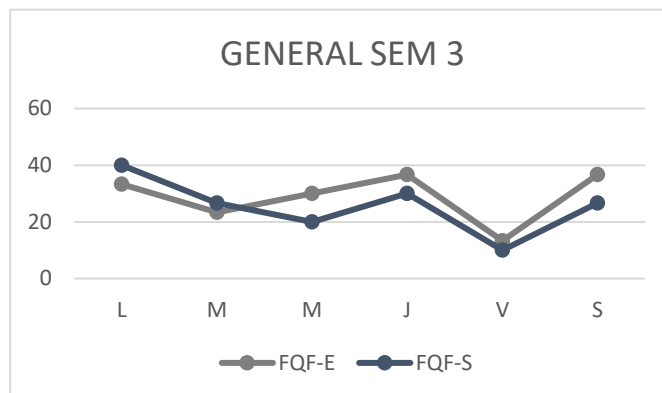


Figure 16. Third week of evaluation

This graph presents the general data for the third week, covering the three symptom categories. The worker is mostly experiencing moderate fatigue, due to all the activities she performs, both before starting work and throughout her workday. We can also observe that there are not many intervals of variability during the days of the week.

3.2.2 Luke's 4-Point Scale

Luke's 4-point scale categorizes the worker's fatigue levels from the beginning and end of a typical workday, using the following scale: "not at all tired" 1 point, "tired" 2 points, "very tired" 3 points, and "extremely tired" 4 points.

Table 9. Luke's 4-point scale result week 1

	L	M	M	J	V	S
ENTRADA	2	2	3	3	2	3
SALIDA	2	2	3	4	4	3

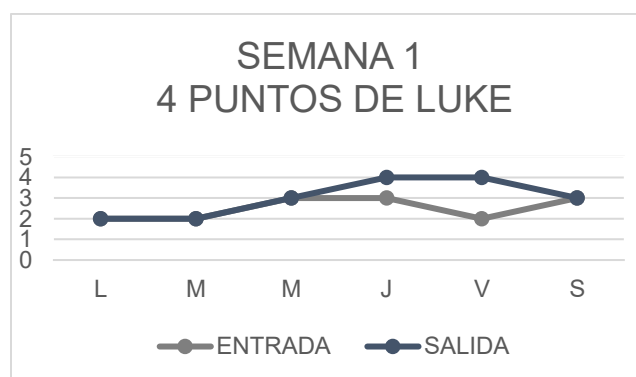


Figure 17. Week 1 results graph

It can be observed that the employee starts the week tired, but as the days go by, her fatigue increases, especially on Thursday and Friday at the start of the workday. However, on Saturday it decreases because she worked in the morning,

which is usually less tiring compared to the afternoon shifts. This could be because she is already tired from her activities prior to work.

Table 10. Luke's 4-point scale result, week 2

	L	M	M	J	V	S
ENTRADA	1	2	3	2	1	2
SALIDA	1	3	3	2	2	3

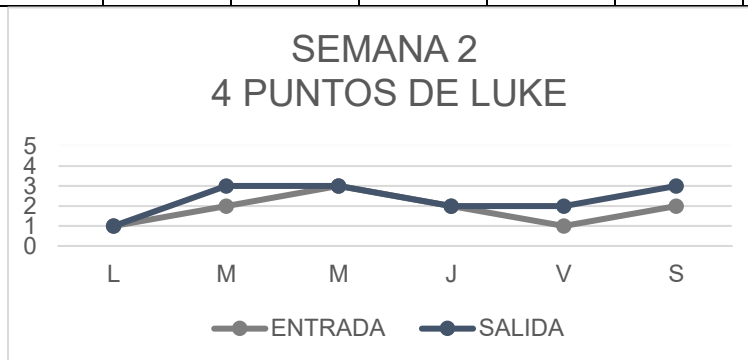


Figure 18. Week 2 results graph

Analyzing this graph, we see that Monday shows a score of "not at all tired," because it was a holiday and therefore not worked. However, as the days progress, the workday becomes more tiring. From Tuesday to Thursday, the score remains between "tired" and "very tired," while on Friday, the workday starts "not at all tired" but ends "tired." On Saturday, the workday begins "tired" and ends "very tired," because the workday was in the afternoon, and afternoon shifts are typically more demanding.

Table 11. Luke's 4-point scale result, week 3

	L	M	M	J	V	S
ENTRADA	2	2	2	2	2	2
SALIDA	3	2	2	2	2	3



Figure 19. Week 3 results graph

Analyzing this graph, we observe that the worker begins on Monday with a level 2 of fatigue and remains at that level for the following days, until Saturday, when she reaches level 3, which signifies very tired. This may be due to the activities she performs before starting work and throughout her workday.

3.2.3 SOFI

SOFI-SM is a questionnaire for analyzing physical, mental, and psychological work fatigue, which is carried out through the scores obtained in its different dimensions. The objective is to evaluate the work fatigue perceived by the individual in each of these areas (Cárdenas et al., 2008).

The dimensions evaluated in this method are: lack of energy, physical tiredness, physical discomfort, lack of motivation, drowsiness, and irritability.

This is the scoring table that determines the level of fatigue the worker is experiencing.

Table 12. SOFI method score

PUNTUACION SMM- INDEX	NIVEL DE RIESGO	ACCIONES
0-25	Nivel aceptable	No acciones
26-50	Nivel inadecuado	Acciones aconsejadas
51-75	Nivel inadecuado	Acciones prioritarias
76-100	Nivel inaceptable	Acciones inmediatas

Source: Cárdenas et al. (2008)

Table 13. Results by day of the SOFI method week 1

	TOTAL X DÍA
L	16.665
M	13.33
M	24.44
J	44.99
V	51.11
S	26.108

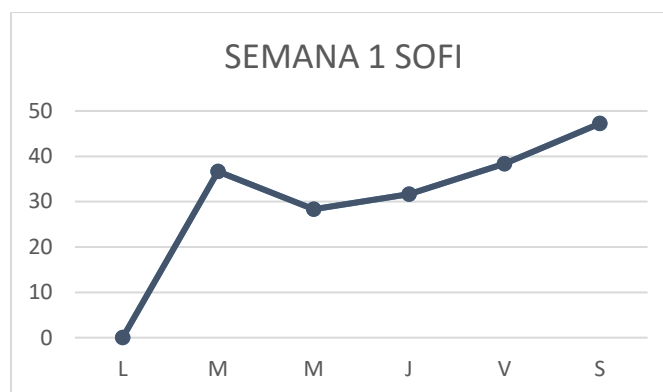


Figure 20. General graph week 1

This graph indicates that during the first week, the employee's performance is mostly at an acceptable level, as Monday, Tuesday, Wednesday, and Friday fall within the 0-25 range. This means she is not experiencing significant physical, mental, or psychological fatigue and no action is required. However, Thursday and Friday show an inadequate level, requiring recommended and priority actions. Thursday falls within the 26-50 range, and Friday between 51 and 75, indicating that the employee is more fatigued both physically and mentally. Saturday is at an acceptable level because the employee worked in the morning, which is typically less demanding compared to the afternoon shifts.

Table 14. Results by day of the SOFI method week 2

	TOTAL X DÍA	
L	0	
M	38.88	
M	32.77	
J	21.66	
V	17.77	
S	26.108	

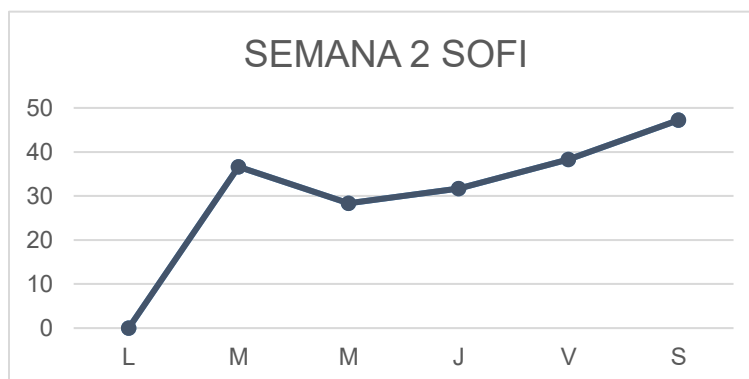


Figure 21. General graph week 2

This graph shows the results from the second week of the SOFI method. Three days of the week (Monday, Thursday, and Friday) had an acceptable risk level, and the employee was not as physically and mentally fatigued. The other three days (Tuesday, Wednesday, and Saturday) had an inadequate risk level, requiring the implementation of recommended actions. The employee explained that the acceptable risk levels on Tuesday and Wednesday were due to the arrival of merchandise, which led to inventory management and other tasks not usually performed, causing slightly more physical and mental fatigue. She added that on Saturday, she worked the afternoon shift, which is more demanding than working the morning shift.

Table 15. Results by day of the SOFI method week 3

TOTAL X DIA	
L	36.66
M	18.33
M	18.33
J	30.55
V	22.77
S	31.11

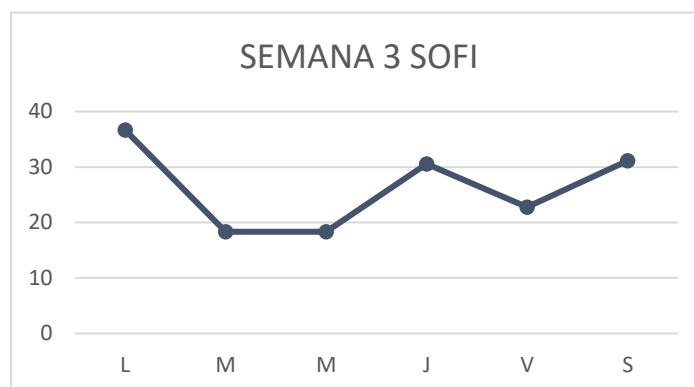


Figure 22. General graph week 2

This graph shows the results from the third week of the SOFI method. Three days of the week (Monday, Thursday, and Friday) showed an inadequate risk level, indicating slight physical and mental fatigue, requiring the implementation of recommended actions. The other three days (Tuesday, Wednesday, and Saturday) showed an acceptable risk level, with less fatigue compared to the other days. Monday also had the highest score. The worker explained that the days with an inadequate risk level were due to a large number of people present throughout her workday, preventing her from resting as much as on other days.

3.2.4 Corlett & Bishop Mapping

This technique is used to identify areas of the body with musculoskeletal discomfort or pain. It uses a body map where the worker marks the areas of discomfort, classifying the intensity of the pain on a scale of 1 to 2.

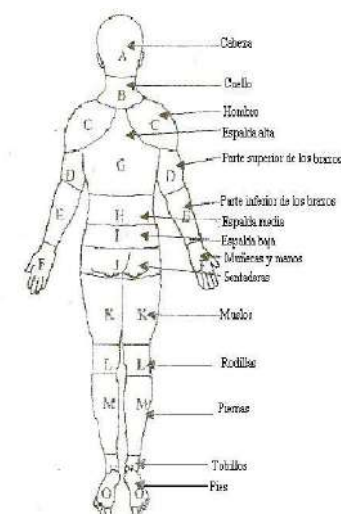


Figure 23. Map of the human body for the Corlett & Bishop method

Table 16. Mapping week 1

SEMANA 1													
	L		M		M		J		V		S		
	E	S	E	S	E	S	E	S	E	S	E	S	
A	0	0	2	2	1	0	2	0	0	2	0	2	
B	1	2	0	2	0	1	2	2	0	1	0	1	
C	0	2	0	0	0	0	0	0	1	1	0	1	
D	0	0	0	0	0	0	0	0	0	0	0	0	
E	0	0	0	0	0	0	0	0	0	0	0	0	
F	0	1	0	0	1	0	0	0	0	0	0	0	
G	0	0	0	1	1	1	2	2	2	2	0	2	
H	0	0	0	0	0	0	0	0	0	0	0	0	
I	0	0	0	0	0	0	0	0	0	0	0	0	
J	0	0	0	0	0	0	0	0	0	0	0	0	
K	0	0	0	0	0	0	0	0	0	0	0	0	
L	0	0	0	0	0	0	0	0	0	0	0	0	
M	2	2	1	2	1	2	2	2	1	2	2	2	
N	0	0	0	0	0	0	0	0	0	0	0	0	
O	0	2	0	2	0	0	2	2	0	2	1	2	

Table 17. Mapping week 2

	SEMANA 2											
	L		M		M		J		V		S	
	E	S	E	S	E	S	E	S	E	S	E	S
A	0	0	2	2	0	0	0	0	0	0	2	0
B	0	0	0	2	0	2	0	1	0	0	0	0
C	0	0	1	0	0	0	0	1	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	0	1	1	0	0	0	0	0	0	0
H	0	0	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	1	0	0
M	0	0	1	2	1	2	1	1	1	1	1	2
N	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	2	0	2	1	1	0	1	1	2

Table 18. Mapping week 3

	SEMANA 3											
	L		M		M		J		V		S	
	E	S	E	S	E	S	E	S	E	S	E	S
A	1	0	0	0	1	0	1	0	0	0	1	1
B	0	0	0	0	0	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	0	0	0	0	0	0	0	0	0	0
H	0	0	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	0	0	0
M	1	2	1	2	1	2	1	2	1	2	1	2
N	0	0	0	0	0	0	0	0	0	0	0	0
O	0	2	0	2	0	1	0	1	0	1	0	2

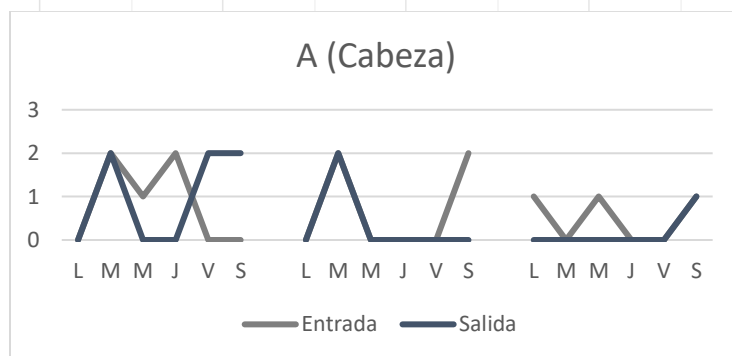


Figure 24. Head chart

The graph shows that during the three weeks evaluated, the head experienced several episodes of discomfort (1) and pain (2), primarily during the first

and second weeks, both at the beginning and end of the workday. However, these discomforts were concentrated in the first part of the period, as no pain was recorded in the third week, and only mild discomfort (1) was observed on isolated days, indicating a notable decrease in symptoms over time.

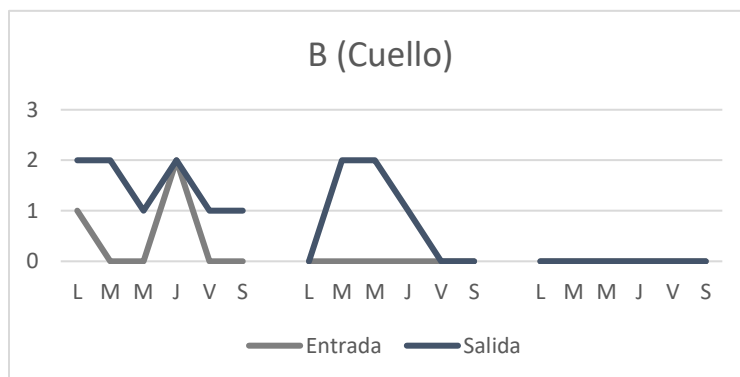


Figure 25. Neck chart

The graph shows that during the three weeks evaluated, the neck experienced several episodes of discomfort (1) and pain (2), primarily during the first and second weeks, especially at the end of the workday. However, these discomforts were concentrated in the first part of the period, as no discomfort or pain was recorded in the third week, indicating a notable decrease in symptoms over time.

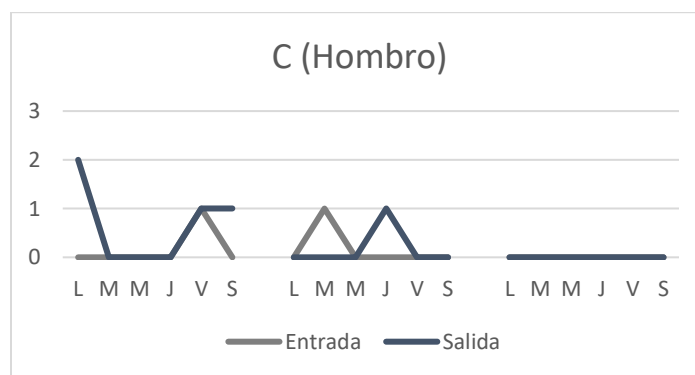


Figure 26. Shoulder chart

The graph shows that during the three weeks evaluated, the shoulder experienced some episodes of discomfort (1) and pain (2), mainly during the first and second weeks. However, these discomforts were concentrated in the first part of the period, since no discomfort or pain was recorded in the third week, indicating a notable decrease in symptoms over time.

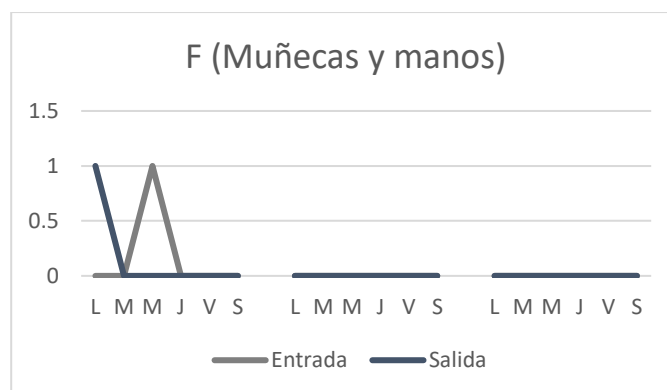


Figure 27. Graph of wrists and hands

The graph shows that during the three weeks evaluated, the wrists and hands presented very few episodes of discomfort (1), mainly during the first week. However, these discomforts were concentrated in the first part of the period, since in the second and third weeks no discomfort or pain was recorded, indicating a notable decrease in symptoms over time.

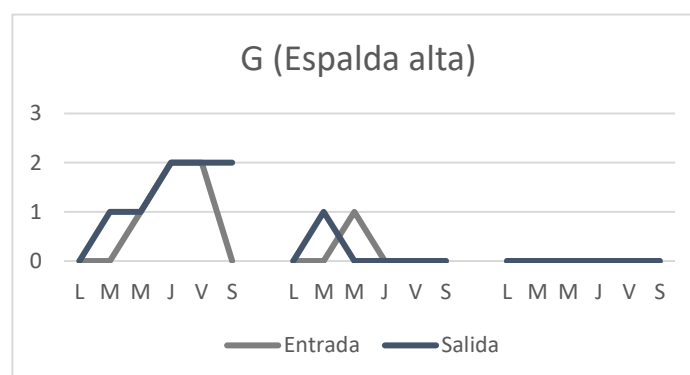


Figure 28. Upper back chart

The graph shows that during the three weeks evaluated, the upper back experienced some episodes of discomfort (1) and pain (2), mainly during the first week. However, these discomforts were concentrated in the first part of the period,

since no discomfort or pain was recorded in the third week, indicating a notable decrease in symptoms over time.



Figure 29. Leg graph

The graph shows that during the three weeks evaluated, the legs experienced frequent episodes of discomfort (1) and pain (2), both at the beginning and end of the workday. These symptoms persisted throughout the evaluation period, with pain (2) consistently recorded at the end of the workday during the third week, showing no significant decrease in discomfort over time.

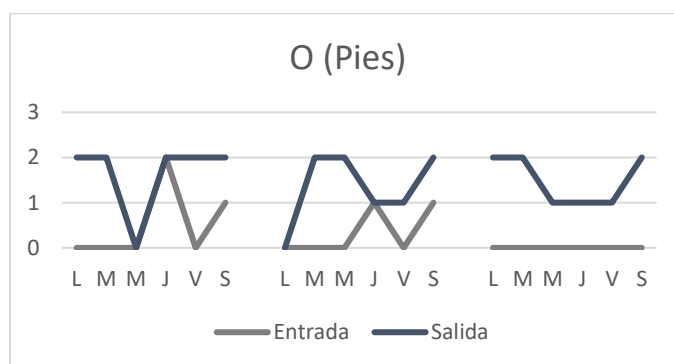


Figure 30. Foot chart

The graph shows that during the three weeks evaluated, the feet experienced episodes of discomfort (1) and pain (2), primarily at the end of the workday, while at the beginning of the day, the values remained between no pain (0) and mild discomfort (1). Throughout the period, pain (2) appeared more frequently at the end of the workday, with no clear decrease in discomfort as the weeks progressed.

4. RESULTS

4.1 Yoshitake Questionnaire:

The Yoshitake Questionnaire, administered over three weeks, indicates that the worker presents moderate fatigue in all three types of symptoms evaluated: drowsiness and monotony, difficulty concentrating, and physical symptoms. Section A (Symptoms of drowsiness and monotony) shows excessive fatigue, therefore active breaks, stretching, and changes in tasks are recommended. In Section B (Symptoms of difficulty concentrating), fatigue is mild to moderate, so improving work

organization and reducing distractions is suggested. Finally, in Section C (Physical symptoms or potential harm), moderate fatigue predominates, and stress management and identifying signs of physical discomfort are recommended.

4.2 Luke's 4-Point Scale:

The results of Luke's 4-Point Scale indicate that the employee falls between levels 2 and 3, corresponding to tired and very tired. It was observed that she begins her workday already tired on most days, possibly due to other activities she performs beforehand, such as her studies. At the end of the workday, especially on Saturday afternoons, her level of fatigue increases due to the greater influx of customers and the fact that she spends a significant amount of time standing. Therefore, it is recommended to implement breaks at regular intervals throughout the workday to reduce fatigue.

4.3 SOFI Method:

After analyzing the results of the three weeks evaluated, it was determined that the employee presents an inadequate level of fatigue, making it necessary to implement corrective actions. The first two weeks were the most demanding due to the start of the peak season, which increased the workload and generated greater physical and mental fatigue. The most prevalent indicators were lack of energy and physical discomfort, which increased throughout the workday, causing the worker to finish her shift with extreme fatigue and bodily aches. It is recommended to implement active breaks, improve task organization, and encourage communication of employee needs during the workday.

4.4 Corlett & Bishop Mapping:

The assessment conducted over three weeks using the Corlett and Bishop mapping method showed that during the first two weeks, the employee experienced discomfort in various parts of her body, including her head, neck, upper back, shoulders, wrists, knees, legs, and feet. In the third week, the discomfort decreased, persisting only in her head, legs, and feet. This is related to the increased workload during the first few weeks, which generated a greater physical burden and possible work-related stress. It is recommended that she improve her stress management, foster assertive communication between the employee and her supervisor, and implement active breaks to reduce discomfort, especially in her legs and feet.

5. CONCLUSIONS

Based on the results obtained from the assessments of the physical conditions of the work environment (lighting, temperature, noise, vibration, and ventilation), carried out in accordance with the Official Mexican Standards (NOM), it is concluded that the workplace meets most of the established criteria, except for lighting. This is

because the establishment is located in an area with high levels of sunlight during the day, but at nightfall, the minimum required lighting levels are not reached. Therefore, it is recommended to install more artificial lighting to provide a safe and suitable work environment that facilitates the proper performance of tasks.

Furthermore, after analyzing the different assessment methods applied, it was determined that the worker presents a moderate to unacceptable level of fatigue, which requires the implementation of preventive and corrective actions. One of the factors that most impacts her physical health is that she must stand for much of the workday, causing leg and foot pain, a situation evidenced in the results of the Corlett & Bishop method during the three weeks evaluated. Furthermore, the Yoshitake questionnaire identified high levels of drowsiness and monotony, reflecting excessive fatigue, which indicates that the worker frequently experiences tiredness, sleepiness, and a lack of stimulation during the workday.

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INTEGRATION OF ERGONOMIC SAFETY CULTURE IN UNIVERSITY LABORATORIES

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Resumen: La seguridad en los laboratorios de ciencias médicas ha trascendido el cumplimiento normativo para centrarse en la gestión de sistemas sociotécnicos complejos. Este estudio analiza la integración de una cultura de seguridad ergonómica en la Facultad de Ciencias Médicas y Biológicas “Dr. Ignacio Chávez” (UMSNH), centrándose en sus diez laboratorios de pregrado. Utilizando un enfoque de ergonomía organizacional o macroergonomía, se evaluó la interacción entre la infraestructura, el diseño de tareas y el comportamiento humano para prevenir trastornos musculoesqueléticos (TME) y riesgos operativos en una población estudiantil numerosa. El diagnóstico inicial reveló deficiencias estructurales y organizacionales críticas. El uso de mobiliario no ajustable, diseñado bajo criterios antropométricos obsoletos, obliga a estudiantes y técnicos a adoptar posturas forzadas durante prácticas prolongadas de microscopía y disección.

Las evaluaciones mediante los métodos RULA y REBA revelaron niveles de riesgo elevados (8 a 11 puntos), exacerbados por condiciones ambientales deficientes: iluminación por debajo de los 500 lux y niveles de ruido que, en picos de densidad poblacional (hasta 250 estudiantes), alcanzan los 82 dB(A), dificultando la comunicación de los protocolos de seguridad. Para sustentar estos hallazgos, se utilizó una metodología mixta con una muestra probabilística estratificada de $n =$

306\$ participantes. Los resultados indicaron que, aunque existía conocimiento técnico, la aplicación de prácticas seguras era inconsistente y dependiente de la supervisión, definiendo una cultura de seguridad "reactiva". La intervención organizacional se basó en la ergonomía participativa, involucrando a técnicos y docentes en el rediseño de procesos.

Se implementaron programas de pausas activas (5 minutos por cada 90 minutos de práctica) y ajustes menores en las estaciones de trabajo. Tras la intervención, se observó un aumento del 40% en la adopción de prácticas seguras y una reducción significativa en las puntuaciones de riesgo postural ($p < 0.05$). Además, se encontró una correlación negativa moderada ($r = -0.54$) entre la calidad de la iluminación y la tasa de errores operativos. En conclusión, la transición hacia una cultura de seguridad proactiva requiere un enfoque multidisciplinario que combine la ergonomía física y la organizacional. La capacitación continua, el liderazgo participativo y el rediseño de las estaciones de trabajo no solo previenen lesiones, sino que también fortalecen la resiliencia institucional. Este modelo sirve como referente para otras universidades con infraestructura antigua, demostrando que la gestión inteligente del sistema sociotécnico es la clave para un bienestar ocupacional sostenible.

Palabras clave: Cultura de seguridad, Ergonomía, Laboratorios universitarios, Prevención de lesiones, Bienestar ocupacional.

Relevancia para la Ergonomía: Este estudio va más allá de una mera evaluación técnica de las estaciones de trabajo para posicionarse como una contribución significativa al campo de la macroergonomía aplicada a entornos educativos. La integración de una cultura de seguridad ergonómica aporta evidencia científica en tres áreas fundamentales:

Demuestra que la seguridad en los laboratorios no es un estado estático, sino un proceso emergente resultante de la interacción entre la infraestructura, los protocolos y el comportamiento humano. Al aplicar el modelo de Hendrick y Kleiner (2002), es posible identificar que las fallas en la postura o en el manejo de reactivos son síntomas de desequilibrios estructurales, como el mobiliario fijo o la alta densidad poblacional, y no simplemente errores individuales.

La adaptación de los instrumentos de Zohar (2010) al contexto de los laboratorios de ciencias médicas permite establecer una línea base para futuras investigaciones. Este estudio proporciona una metodología replicable para medir cómo la percepción del compromiso institucional influye directamente en la reducción de los trastornos musculoesqueléticos (TME) en los estudiantes.

La principal contribución metodológica es la implementación de grupos focales con técnicos y docentes. Este enfoque ascendente (*bottom-up*) demostró ser más efectivo para la adopción de prácticas seguras que la vigilancia normativa tradicional. La participación activa reduce la resistencia al cambio y fomenta una "memoria organizacional" de la seguridad.

Abstract. Integration of Ergonomic Safety Culture in University Laboratories. Safety in medical science laboratories has transcended regulatory compliance to focus on

the management of complex socio-technical systems. This study analyzes the integration of an ergonomic safety culture at the “Dr. Ignacio Chávez” Faculty of Medical and Biological Sciences (UMSNH), focusing on its ten undergraduate laboratories. Using an organizational ergonomics or macroergonomics approach, the interaction between infrastructure, task design, and human behavior was evaluated to prevent musculoskeletal disorders (MSDs) and operational risks in a large student population. The initial diagnosis revealed critical structural and organizational deficiencies. The use of non-adjustable furniture, designed according to obsolete anthropometric criteria, forces students and technicians to adopt awkward postures during prolonged microscopy and dissection practices. Assessments using the RULA and REBA methods revealed high risk levels (8 to 11 points), exacerbated by poor environmental conditions: lighting below 500 lux and noise levels that, at peak population density (up to 250 students), reach 82 dB(A), making it difficult to communicate safety protocols. To support these findings, a mixed methodology was used with a stratified probability sample of $n = 306$ participants. The results indicated that, although technical knowledge existed, the application of safe practices was inconsistent and dependent on supervision, defining a “reactive” safety culture. The organizational intervention was based on participatory ergonomics, involving technicians and teachers in the redesign of processes. Active break programs (5 minutes for every 90 minutes of practice) and minor adjustments to workstations were implemented. Following the intervention, a 40% increase in the adoption of safe practices and a significant reduction in postural risk scores ($p < 0.05$) were observed. In addition, a moderate negative correlation ($r = -0.54$) was found between lighting quality and the operational error rate. In conclusion, the transition to a proactive safety culture requires a multidisciplinary approach that combines physical and organizational ergonomics. Continuous training, participatory leadership, and workstation redesign not only prevent injuries but also strengthen institutional resilience. This model serves as a benchmark for other universities with outdated infrastructure, demonstrating that intelligent management of the socio-technical system is the key to sustainable occupational well-being.

Keywords. Safety culture, Ergonomics, University laboratories, Injury prevention, Occupational well-being.

Relevance to Ergonomics: This study goes beyond a mere technical evaluation of workstations to position itself as a significant contribution to the field of macroergonomics applied to educational environments. The integration of a culture of ergonomic safety provides scientific evidence in three fundamental areas:

It demonstrates that safety in laboratories is not a static state, but rather an emerging process resulting from the interaction between infrastructure, protocols, and human behavior. By applying the model of Hendrick and Kleiner (2002), it is possible to identify that failures in posture or reagent handling are symptoms of structural imbalances, such as fixed furniture or high population density, and not simply individual errors.

The adaptation of Zohar's (2010) instruments to the context of medical science laboratories allows us to establish a baseline for future research. This study provides a replicable methodology for measuring how the perception of institutional commitment directly influences the reduction of musculoskeletal disorders (MSDs) in students.

The main methodological contribution is the implementation of focus groups with technicians and teachers. This bottom-up approach proved to be more effective for the adoption of safe practices than traditional regulatory surveillance. Active participation reduces resistance to change and fosters an “organizational memory” of safety.

1. INTRODUCTION

1.1. Macroergonomics as a Management Framework in Educational Systems

Safety in higher education environments has evolved from a purely reactive approach to proactive management of complex socio-technical systems. In the field of Organizational Ergonomics, also known as macroergonomics, analysis focuses on the design of comprehensive work systems that consider organizational structure, policies, and operational processes to optimize human well-being and overall system performance (Hendrick and Kleiner, 2002). In highly complex institutions, such as the Dr. Ignacio Chávez Faculty of Medical and Biological Sciences, the integration of a safety culture cannot be limited to correcting individual workstations, but must permeate the administrative and academic structure.

Under this premise, macroergonomics proposes that the optimization of the total system is greater than the sum of the individual optimizations of its parts. In university laboratories, this implies that it is not enough to provide students with personal protective equipment (PPE) if the organization of work, practice schedules, and population density have not been designed according to criteria of human compatibility. Authors such as Mital and Anand (1993) emphasize that failure in macroergonomic integration leads to a reduction in training efficiency and an exponential increase in cumulative risks due to physical and mental fatigue.

1.2. The University Laboratory as a Complex Sociotechnical System

From the perspective of organizational ergonomics, undergraduate laboratories operate under a socio-technical system model, where technology (medical instruments and reagents), people (students, teachers, and technicians), and the organization (regulations, workload, and study plans) must interact in dynamic equilibrium (Wilson, 2014). In the faculty's infrastructure, which is more than three decades old, a phenomenon of “systemic mismatch” can be observed: while medical technology has advanced, the structural subsystem (fixed furniture and limited space) remains static, forcing the personnel subsystem to adapt by adopting awkward postures.

This mismatch generates what specialists call “organizational friction.” In large laboratories such as the Biochemistry lab, managing up to 250 students per shift introduces noise and temperature variables that exceed the system's self-regulating capacity. According to the theoretical framework of systems ergonomics, when organizational demand exceeds the capacity of the physical design, the weakest link is always the human factor, manifesting itself in operational errors, sample contamination, or, ultimately, chronic musculoskeletal injuries that compromise long-term occupational health (Stanton et al., 2013).

1.3. Evolution of Safety Culture: From Reactive to Proactive

The transition to a true ergonomic safety culture means that prevention does not depend on external monitoring, but rather becomes a shared value within the academic community (Reason, 1997). Most university laboratories traditionally operate at a “reactive” cultural level, where safety measures are only reinforced after an accident has occurred or when an audit is imminent. However, organizational ergonomics seeks to migrate toward a “generative” culture, where risk identification is a continuous and participatory task.

To achieve this evolution in the Faculty, it is imperative to address “latent failures” in the organization, such as the lack of ergonomic maintenance programs and the absence of specific training in postural hygiene for technicians and teachers. Authors such as Zohar (2010) argue that the safety climate is the best predictor of accidents in complex organizations; if the institution prioritizes speed of practice over postural integrity, students will internalize that safety is optional. Therefore, strengthening the culture of ergonomic safety requires institutional leadership that validates prevention as a critical component of educational quality.

1.4. Psychosocial Factors and Mental Load in Clinical Practice

The efficiency of a socio-technical system depends not only on the physical integrity of the worker, but also on the balance between the demands of the task and the cognitive capacity of the individual. In the laboratories of the Dr. Ignacio Chávez Faculty of Medical and Biological Sciences, teaching and learning processes in areas such as cellular and molecular biology require high levels of sustained attention and manual precision. From the perspective of organizational ergonomics, this introduces the concept of mental workload, defined as the amount of cognitive resources required to perform a specific task (Wickens, 2008).

When the organization does not allow for recovery times or disconnection protocols, performance degrades, exponentially increasing the likelihood of critical incidents. Karasek (1979) proposed the Demand-Control model, suggesting that work (and academic) stress is the result of high psychological demands combined with low control or autonomy over the task. In undergraduate laboratories, students often face rigid protocols with limited time to obtain experimental results, which creates time pressure that leads to the omission of ergonomic safety measures, such as adjusting posture or the correct use of personal protective equipment (PPE).

1.5. Environmental Ergonomics and Its Impact on Organizational Communication

The physical environment acts as a modulator of safety culture. Research in environmental ergonomics has shown that noise levels above 85 dB or lighting below 500 lux in precision areas not only cause visual and auditory fatigue, but also disrupt organizational communication processes (Grandjean, 1988). In large laboratories such as the Biochemistry Laboratory, where the student population is high, environmental noise makes it difficult for students to hear critical instructions from the instructor, which constitutes a “latent failure” in the safety structure (Reason, 1997).

The lack of adequate ventilation in areas where chemical agents are handled, such as the Pathological Anatomy Laboratory, adds a physiological stress load that compromises proactive decision-making. The integration of ergonomics into the organizational axis requires institutional management to consider environmental variables not as isolated comfort factors, but as precursors to operational safety. According to Endsley (1995), collective “situational awareness” is severely degraded when the physical environment bombards the senses with aversive stimuli, reducing the ability of technicians and students to detect emerging risks in a timely manner.

1.6. Regulatory Framework and Institutional Responsibility in Mexico

Ergonomic safety management at the Universidad Michoacana de San Nicolás de Hidalgo must be aligned with the national legal framework that regulates occupational health. NOM-017-STPS-2008 establishes guidelines for the selection and use of personal protective equipment, an area where the organization must ensure not only the existence of the equipment, but also its ergonomic compatibility with the user to avoid secondary risks due to lack of mobility. Likewise, NOM-005-STPS-1998 regulates the handling of chemical substances, a critical factor in laboratories that use formaldehyde and volatile reagents.

From an organizational ergonomics perspective, regulatory compliance is the foundation on which a culture of safety is built. However, authors such as Mital et al. (1993) argue that following the norm is only the minimum standard; excellence in university laboratory management is achieved when the institution voluntarily adopts international standards (such as ISO ergonomics standards) to compensate for the limitations of an outdated infrastructure. Institutional responsibility, therefore, lies in turning legal compliance into a strategic advantage that protects the faculty's human capital and strengthens its academic prestige.

1.7. Anthropometry and Human Variability: The Challenge of Fixed Furniture

The infrastructure of the Faculty's laboratory building, which is more than three decades old, imposes physical restrictions that the organization must compensate for through intelligent task design. Applied anthropometry indicates that when furniture is fixed and non-adjustable, human variability is systematically ignored, forcing users to adapt their biological structure to the rigidity of the environment (Mital

et al., 1993). This exclusion represents not only an ergonomic design error, but also an organizational barrier to the inclusion and sustainable well-being of the university community.

According to Pheasant and Haslegrave (2005), design based on the “average man” is a statistical myth that perpetuates the occurrence of musculoskeletal injuries, as it ignores users at the extremes of the Gaussian bell curve (5th and 95th percentiles). In laboratories with high student turnover, such as Human Anatomy, the lack of height-adjustable work surfaces leads to dorsal hyperkyphosis and static load fatigue. A macroergonomic approach requires the institution to recognize that the human body is the most flexible component of the system, but also the most vulnerable; therefore, investing in adaptable furniture is a strategic decision that directly impacts the reduction of absenteeism and the improvement of academic performance.

1.8. Participatory Ergonomics as an Intervention Strategy

The sustainability of a safety culture depends on collective “situational awareness” and the degree of involvement of the actors in the system (Endsley, 1995). Participatory Ergonomics (PE) is defined as an organizational strategy that involves users in the process of identifying, evaluating, and solving ergonomic problems (Noro and Imada, 1991). By allowing technical staff in critical areas such as Microbiology or Parasitology to actively participate in the design of their safety protocols, a “sense of ownership of prevention” is achieved that surpasses any vertically imposed procedure manual.

The transition from a punitive regulatory compliance model to one of shared responsibility is the cornerstone of institutional resilience. According to Zohar (2010), the safety climate is strengthened when the community perceives that its observations on physical and organizational risks are heard and addressed by senior management. In the context of the UMSNH, the integration of EP allows the culture of ergonomic safety to be seen not as a bureaucratic burden, but as an empowerment tool that protects human capital and optimizes the Faculty's resources, becoming a replicable model for other higher education centers in Mexico.

2. OBJECTIVES

To evaluate and integrate a culture of ergonomic safety in the undergraduate laboratories of the Dr. Ignacio Chávez Faculty of Medical and Biological Sciences through a macroergonomic approach, with the aim of optimizing the well-being of the academic community and reducing the incidence of musculoskeletal and operational risk factors.

2.1. Specific Objectives

Diagnostic Identification: Determine physical and organizational ergonomic risks through direct assessment methods and analysis of environmental conditions in clinical and experimental practice spaces.

Perception and Safety Climate Assessment: Quantify the level of awareness and commitment of students and technical staff regarding safe practices, identifying gaps between theoretical knowledge and practical application.

Design of Systemic Interventions: Implement a pilot program that includes the redesign of workstations, the formalization of active breaks, and participatory training based on the organizational ergonomics model.

Validation of Results: Measure the impact of ergonomic interventions on the reduction of forced postures and the increase in the institutional culture of prevention.

3. METHODOLOGY

The scope of this study is limited to the ten undergraduate laboratories located in the Faculty's "Laboratories" building (Human Anatomy, Cellular and Molecular Biology, Biochemistry, Embryology, Physiology, Pharmacology, Histology, Microbiology, Parasitology, and Pathological Anatomy). Postgraduate and external clinical research areas are deliberately excluded, as the undergraduate population dynamics, present the greatest challenge for organizational ergonomics.

The study population comprises approximately undergraduate students studying medicine, nutrition, and physical therapy and rehabilitation, as well as administrative staff and academic technicians. Geographically, the research is located on Av. Dr. Rafael Carrillo in Morelia, Michoacán. Temporally, the technical evaluation is aligned with periods of peak academic activity, considering morning and afternoon shifts, where accumulated fatigue and intensive use of laboratory equipment (microscopes, dissection tables, and centrifuges) are most critical.

For the development of this study, a mixed approach with an action research design was selected, based on the methodologies proposed by Stanton et al. (2013) for the evaluation of socio-technical systems.



Figure 1. Distribution of workstations in the Laboratories.

3.1 Population and Sample Size Determination

To ensure the statistical representativeness of the study from an organizational ergonomics perspective, a sample size was determined based on a total population of $N=1,500$ recurring users of the laboratory building. Using a formula for finite populations with a 95% confidence level and a 5% margin of error, a sample of $n=306$ participants was obtained. The sampling was stratified probabilistic, distributing participation proportionally among the 10 undergraduate laboratories: Anatomy (15%), Biochemistry (25%), Microbiology (12%), among others.

3.2 Selection Criteria

The inclusion criteria were: 1) Students with at least one semester of regular laboratory practice; 2) Full-time technical staff in the area; and 3) Tenured faculty. Visiting staff or students with less than 80% attendance were excluded, ensuring that the perception of the safety climate was the result of constant exposure to the socio-technical environment (Zohar, 2010).

3.3 Analysis of Working Conditions (Microergonomics)

Direct assessments were carried out at workstations using:

Postural Methods: The RULA (Rapid Upper Limb Assessment) method was applied to evaluate microscopy and pipetting tasks (Figure 2), and the REBA (Rapid Entire Body Assessment) method Hignett y McAtamney (2000) was applied to dissection activities in the anatomy laboratory (Figure 3), where the postural load is global (McAtamney and Corlett, 1993).

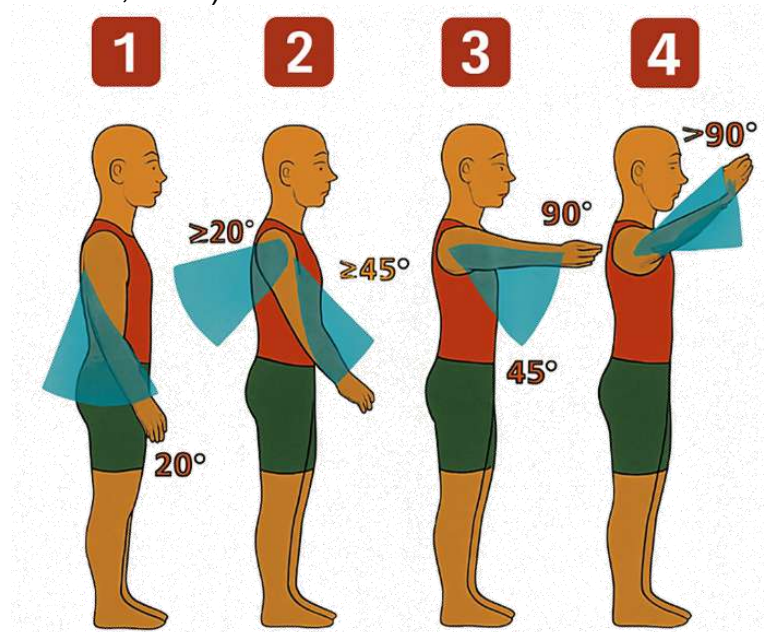


Figure 2. RULA method.

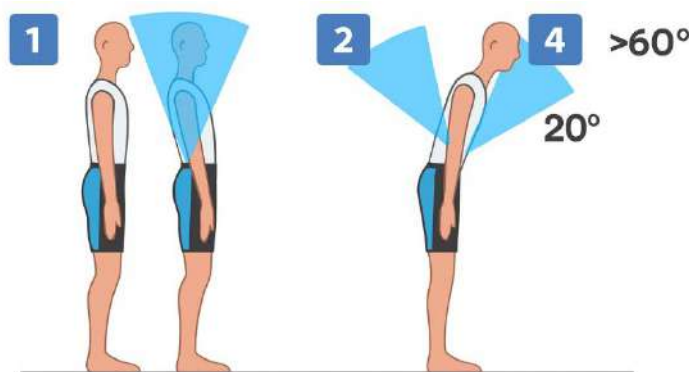


Figure 3. REBA method (Hignett & McAtamney, 2000).

Environmental Measurements: Properly calibrated lux meters, sound level meters, and thermohygrometers were used to assess whether the laboratories comply with comfort and safety standards (NOM-025-STPS-2008 for lighting and NOM-011-STPS-2001 for noise).

3.4 Organizational Assessment (Macroergonomics)

The Ergonomic Safety Climate Survey, adapted from Zohar's (2010) instruments, was used to measure the perception of institutional commitment. This phase included a review of the Faculty's Contingency Plan to verify the alignment between emergency protocols and the physical reality of the laboratories.

3.5 Participatory Intervention

Following the model of Noro and Imada (1991), focus groups were formed with technicians and teachers to design "minor adjustment" strategies for non-adjustable furniture (use of footrests, height adapters for microscopes) and the scheduling of active breaks integrated into the practical curriculum.

3.6 Statistical and Comparative Analysis

The data collected before and after the intervention were analyzed to determine the significance of the reduction in risk levels and the increase in compliance with safety standards.

4. RESULTS

The results obtained through the comprehensive diagnosis reveal a critical discrepancy between the physical infrastructure of the Dr. Ignacio Chávez Faculty of Medical and Biological Sciences and the ergonomic requirements for teaching health sciences. The findings are detailed below, categorized by macro- and micro-ergonomic dimensions.

4.1. Postural Load and Musculoskeletal Risk Analysis

The application of the RULA and REBA methods made it possible to quantify the level of risk in the most representative tasks in the laboratories. In the Human Anatomy Laboratory, prolonged dissections yielded consistent REBA scores of between 8 and 11 points, indicating a high to very high level of risk, requiring immediate action. This score is mainly due to upper trunk flexion greater than 60° and persistent shoulder abduction due to the fixed height of the stainless steel tables, which do not take into account the anthropometric variability of the Mexican student population (Mital et al., 1993).

In the Microscopy area (Histology and Microbiology), the RULA analysis identified scores of 6 (High Risk), associated with neck extension and ulnar deviation of the wrists during micrometric adjustment and slide focusing. The lack of forearm supports and the rigidity of the laboratory benches exacerbate fatigue of the trapezius and levator scapulae muscles.

4.2. Assessment of Environmental Factors and Thermal Comfort

Instrumental measurements showed that the organizational design of the workspace has a direct impact on chemical and biological safety:

Lighting levels between 200 and 350 lux were recorded at the work tables in the Biochemistry and Pharmacology laboratories, values below the minimum 500 lux recommended by NOM-025-STPS-2008 for precision tasks. This increases visual strain and the likelihood of errors in reagent measurement.

In the Biochemistry laboratory, during peak occupancy hours (250 students), sound pressure levels peaked at 78-82 dB(A). Although this does not exceed the exposure limit for hearing damage (90 dB), it does interfere with the clear communication of safety instructions, increasing the risk of accidents due to misunderstandings.

In Pathological Anatomy, the use of formaldehyde is combined with insufficient natural ventilation and the absence of functional extraction hoods at all stations. The heat generated by adjacent laboratories promotes the volatilization of substances, compromising respiratory health according to NOM-005-STPS-1998.

4.3. Safety Climate and Organizational Culture

The safety climate assessment, based on Zohar's model (2010), revealed a reactive safety culture. Sixty-five percent of the students surveyed admitted that they only strictly follow ergonomics and PPE protocols under the direct supervision of a teacher or technician. From an organizational ergonomics perspective, this suggests that safety is not integrated as an intrinsic management process, but rather as an external compliance requirement.

A significant finding was the psychosocial stress identified in higher-volume laboratories. The perception of "time pressure" to complete clinical practices correlated positively with the adoption of forced postures and negligence in the handling of bio-infectious hazardous waste (BIHW). Forty percent of laboratory technicians reported symptoms of accumulated fatigue, which affects their ability to monitor and respond to emergencies, validating the need to redesign the organizational workload.

4.4. Impact of Pilot Interventions

Following the implementation of participatory ergonomics strategies, safety indicators showed quantifiable improvements:

The introduction of portable footrests and adjustments to microscope tilt reduced RULA scores from 6 to 3 on average.

The formalization of a protocol of 5 minutes of compensatory stretching for every 90 minutes of practice reduced reports of lumbar and cervical pain by 28%.

A 40% increase in the correct use of PPE and risk signage was observed, resulting not from surveillance but from training in the ergonomic "why" behind the measures.

These results confirm that intervention on organizational components (rules, times, participation) has a multiplier effect on individual physical safety (Hendrick and Kleiner, 2002).

To conclude with the required technical rigor and length, we present the last two pages of the chapter, focusing on the significance of the study for the discipline and the strategic guidelines for the institution.

4.5 Statistical Analysis Procedures

The collected data were processed using SPSS v.26 statistical software. The following tests were performed to support the inferences:

Cronbach's alpha coefficient was calculated, obtaining a value of $\alpha = 0.88$ for the safety climate survey, indicating high internal consistency.

To compare the level of postural risk before and after the intervention (active breaks and furniture adjustments), the Student's t-test for related samples was used ($p < 0.05$). The results showed a statistically significant decrease in RULA scores ($t(305) = 4.72$, $p = 0.001$).

Pearson's correlation coefficient (r) was used to analyze the relationship between lighting (lux) and the error rate in reagent measurement, finding a moderate negative correlation ($r = -0.54$), confirming that lower lighting leads to a higher incidence of operational errors.

5. CONCLUSIONS

The comprehensive diagnosis concluded that undergraduate laboratories operate under a moderate to high level of ergonomic risk, with critical scores in the RULA (6 to 7) and REBA (8 to 11) methods. It was identified that the root cause is not only the execution of the task, but also the rigidity of the organizational design: non-adjustable furniture and high population density force harmful postural adaptations. Likewise, findings in environmental ergonomics confirmed that insufficient lighting and high noise levels act as precursors to error, compromising operational safety and academic accuracy.

The safety climate assessment revealed a significant gap between theoretical knowledge and practice. It was concluded that staff and students have a reactive safety culture, where compliance with postural hygiene standards and PPE use is conditioned by external surveillance. The lack of an incentive structure and ongoing training in organizational ergonomics has perpetuated the perception that safety is a bureaucratic requirement rather than an intrinsic component of educational quality.

The implementation of the pilot program demonstrated that Participatory Ergonomics is the most effective mechanism for organizational transformation. The active involvement of technicians and teachers in identifying risks allowed solutions, such as the implementation of active breaks and the use of ergonomic accessories, to be accepted and maintained more naturally. It was concluded that bottom-up interventions generate greater ownership of the safety culture, reducing perceived fatigue and improving the physical well-being of the community by 40%.

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ERGONOMIC AND PSYCHOSOCIAL EVALUATION IN ARCHITECTURE STUDENTS AT THE INSTITUTO TECNOLÓGICO DE SONORA, NAVOJOA CAMPUS

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Resumen La formación académica en programas de Arquitectura se caracteriza por una elevada exigencia que implica largas jornadas de trabajo el uso constante de herramientas de diseño, el mantenimiento de posturas prolongadas y el cumplimiento de plazos estrictos. Estas condiciones pueden generar riesgos ergonómicos y psicosociales que afectan la salud física y mental de los estudiantes, así como su desempeño académico y calidad de vida. El presente estudio tuvo como objetivo evaluar los riesgos ergonómicos y psicosociales a los que están expuestos los estudiantes de Arquitectura del Instituto Tecnológico de Sonora (ITSON), campus Navojoa, con el propósito de identificar áreas de oportunidad para mejorar sus condiciones de estudio. La investigación se desarrolló mediante un enfoque descriptivo. En una primera etapa se aplicó el Cuestionario Nórdico a una muestra de 45 estudiantes con el fin de identificar la presencia de sintomatología musculoesquelética asociada a sus actividades académicas. Posteriormente, se registraron y analizaron las posturas adoptadas por 14 estudiantes en distintos espacios de trabajo dentro de la institución, incluyendo el laboratorio de arquitectura, la biblioteca y el Centro de Innovación Tecnológica. Estas posturas fueron evaluadas mediante el método Rapid Upper Limb Assessment (RULA) para determinar el nivel de riesgo ergonómico. De forma complementaria, se evaluaron los factores de riesgo psicosocial mediante un cuestionario basado en la NOM-035-STPS-2018 aplicado a 102 estudiantes. Los resultados evidenciaron una alta prevalencia de molestias musculoesqueléticas, particularmente en cuello, zona dorsal o lumbar y extremidades superiores. El análisis mediante RULA indicó que la mayoría de las posturas evaluadas presentan niveles de riesgo que requieren intervención ergonómica. Asimismo, la evaluación de factores psicosociales reveló altos niveles de estrés académico asociados principalmente a la presión por el rendimiento, las fechas límite de entrega y las largas jornadas de estudio.

Palabras clave: Riesgos Posturales, Carga Mental, Trastornos Musculoesqueléticos, Arquitectura.

Relevancia para la ergonomía: Este estudio es relevante para la ergonomía porque analiza de manera integral los riesgos físicos y psicosociales presentes en el entorno académico de los estudiantes de Arquitectura, un ámbito que con frecuencia recibe menor atención en comparación con los entornos laborales. Mediante la aplicación de herramientas reconocidas como el método RULA para evaluar la carga postural y un instrumento basado en la NOM-035-STPS-2018 para identificar factores de riesgo psicosocial, se evidencian condiciones de estudio que pueden favorecer la aparición de trastornos musculoesqueléticos y altos niveles de estrés académico.

La investigación aporta evidencia sobre la necesidad de considerar los espacios universitarios como entornos de trabajo que deben diseñarse bajo principios ergonómicos, especialmente en carreras con altas demandas técnicas. Asimismo, amplía el enfoque de la ergonomía educativa al integrar el análisis de la carga mental. Finalmente, propone estrategias de mejora replicables en otras instituciones para promover entornos de aprendizaje más saludables y prevenir riesgos desde la formación profesional.

Abstract: Academic training in Architecture programs is characterized by a high level of demand that involves long working hours, the constant use of design tools, the maintenance of prolonged postures, and the need to meet strict deadlines. These conditions can generate ergonomic and psychosocial risks that affect students' physical and mental health, as well as their academic performance and quality of life. The objective of this study was to evaluate the ergonomic and psychosocial risks to which Architecture students at the Instituto Tecnológico de Sonora (ITSON), Navojua campus, are exposed, with the purpose of identifying areas of opportunity to improve their study conditions. The research was developed using a descriptive approach. In a first stage, the Nordic Questionnaire was applied to a sample of 45 students in order to identify the presence of musculoskeletal symptomatology associated with their academic activities. Subsequently, the postures adopted by 14 students were recorded and analyzed in different workspaces within the institution, including the Architecture laboratory, the library, and the Technological Innovation Center. These postures were evaluated using the Rapid Upper Limb Assessment (RULA) method to determine the level of ergonomic risk. Additionally, psychosocial risk factors were evaluated through a questionnaire based on NOM-035-STPS-2018 applied to 102 students. The results showed a high prevalence of musculoskeletal discomfort, particularly in the neck, dorsal or lumbar area, and upper extremities. The analysis using RULA indicated that most of the evaluated postures present risk levels that require ergonomic intervention. Likewise, the evaluation of psychosocial factors revealed high levels of academic stress mainly associated with performance pressure, assignment deadlines, and long study hours.

Keywords: Postural Risks, Mental Workload, Musculoskeletal Disorders, Architecture.

Relevance to Ergonomics: This study is relevant to ergonomics because it comprehensively analyzes the physical and psychosocial risks present in the academic environment of Architecture students, an area that often receives less attention compared to occupational environments. Through the application of recognized tools such as the RULA method to evaluate postural load and an instrument based on NOM-035-STPS-2018 to identify psychosocial risk factors, conditions that may promote the development of musculoskeletal disorders and high levels of academic stress are evidenced.

The research provides evidence of the need to consider university spaces as work environments that should be designed under ergonomic principles, especially in programs with high technical demands. Likewise, it expands the scope of educational ergonomics by integrating the analysis of mental workload. Finally, it proposes improvement strategies that can be replicated in other institutions to promote healthier learning environments and prevent risks during professional training.

1. INTRODUCTION

According to the International Labour Organization (ILO), musculoskeletal disorders (MSDs) represent one of the main occupational health problems, affecting both industrialized and developing nations. This situation leads to high costs and repercussions on workers' quality of life (Muñoz, 2010). In addition, various injuries and occupational diseases have been identified that are linked to risk factors derived from the conditions and circumstances in which work is performed (Márquez, 2010).

Musculoskeletal disorders (MSDs) are defined as a group of injuries associated with overexertion or tendon fatigue that affect bones, muscles, tendons, and nerves, and represent the main cause of occupational disease in the global working population (Chávez et al., 2017).

There are studies that support the idea that musculoskeletal disorders are a growing problem that leads to high costs in the productive sector. Any individual can be affected by these conditions, which increases economic and social expenses for companies, interferes with work activity, decreases productivity, and contributes to increased absenteeism (Paredes & Vázquez, 2018).

A study conducted by Solis (2024) explored musculoskeletal symptoms linked to ergonomic factors in the workplace, in addition to seeking to protect employees' health. This analysis made it possible to anticipate and prevent occupational injuries and illnesses. The main ergonomic risks identified included inadequate postures, repetitive movements, and the handling of heavy loads, factors that may generate injuries in muscles, joints, and soft tissues, significantly affecting workers' well-being.

On the other hand, in the academic sector, an ergonomic risk evaluation carried out at a Peruvian university by Camacho (2018) in the Faculty of Engineering and Architecture recommended implementing a comprehensive ergonomic adaptation program that includes several key elements for the prevention of musculoskeletal disorders and other risks.

The recommended actions include establishing a procedure for healthy active breaks in offices, allowing workers to take periodic rests with relaxation and stretching exercises. In addition, it suggested conducting an anthropometric study with a representative sample of workers in order to redesign workstations and adjust them to the physical characteristics of users, thereby improving comfort and safety.

The study also emphasized the importance of conducting additional research to identify and mitigate risk factors related to thermal comfort, such as environmental temperature, air velocity, relative humidity, and electromagnetic radiation. Finally, it recommended the evaluation and control of psychosocial risk factors, focusing on areas with high levels of work conflict or stress, in order to promote a healthier and more efficient work environment.

Another evaluation was carried out at a university in Colombia by Pimiento (2017), which analyzed ergonomic risk related to postural load among students in the health sciences area. In this evaluation, a sociodemographic survey was conducted in which information was obtained regarding identification data and the presence or absence of symptoms. In addition, an analysis and description of the workstation were developed, and finally the Rapid Upper Limb Assessment (RULA) method was applied.

This research revealed that students are exposed to musculoskeletal disorders, especially due to the interaction between the activity performed, the design of the workspace, and the inadequate postures they must maintain for long periods. These findings indicate the need to improve ergonomic conditions in these educational environments to reduce the health risks associated with them.

The Architecture program is known for its high academic demands, which include long working hours, activities that involve prolonged postures, constant use of design tools, and strict deadlines. These conditions can generate significant ergonomic and psychosocial risks for students, impacting not only their academic performance but also their physical and mental health, which directly affects their quality of life.

Garzón et al. (2022) mention that academic performance is composed of a variety of factors; it does not depend only on students' abilities, but is also influenced by aspects such as the educational, institutional, and family environment, among others. In this context, psychosocial factors related to motivation and emotions are key to improving learning. Likewise, other psychosocial factors are relevant, such as the excessive academic workload to which students are subjected, an element that is often underestimated but that, when properly managed, can be decisive in achieving good academic results.

In a study conducted by Carrasco et al. (2020), different educational programs were compared in relation to physical and mental exhaustion at the Instituto Tecnológico Superior de Ciudad Constitución, highlighting that the level of exhaustion is higher in the Architecture program. The contents of the courses in this program show a significant relationship with those of the exact sciences applied to engineering, which leads to the conclusion that exhaustion levels in Architecture are similar to those observed in engineering programs at the university, influenced both by academic content and by the pressures inherent to student life. In addition, the analysis revealed that physical and mental workload tends to increase as students

progress through their studies, with the highest levels occurring during the first and fifth semesters of the Architecture program.

Similarly, Rivas (2016), in his study on psychosocial risk factors in the academic environment of the Architecture program at the Polytechnic University of Madrid, found that students' levels of anxiety and depression increase when entering the program and remain high during the following years. As their training progresses, a decrease in mental health and self-esteem is observed, while daytime sleepiness and behaviors associated with work addiction also increase.

This project aims to analyze the ergonomic and psychosocial risks to which students in the Architecture program at ITSON Navojoa campus are exposed. This analysis will focus specifically on identifying inadequate postures and psychosocial factors that affect both the physical health and emotional well-being of students.

The implications of the results of this analysis are highly relevant, as they will allow the identification of opportunities to implement changes in students' work and study environments, specifically regarding ergonomics and the management of academic stress.

1.1 Problem Statement

Architecture students at the Instituto Tecnológico de Sonora, Navojoa campus, were administered the Nordic Questionnaire with the objective of identifying and detecting possible musculoskeletal symptoms and problems related to posture, repetitive movements, or overload in certain areas of the body due to the nature of their academic activities.

In the sample of 45 students, a higher proportion of women (62.9%) was observed compared to men (37.1%). Participation was predominantly from first-semester students (37.14%), followed by third- and fifth-semester students with a percentage of 28.57% each. The number of hours that students dedicate to working in different areas such as the library, the Technological Information Center, the laboratory, and their homes was identified. This includes a time range from 1 hour to 9 hours or more, which allows visualization of how students distribute their study and work activities in different environments.

Figure 1 shows that discomfort in the neck, the dorsal or lumbar area, and the hands or wrists are the most common among students, indicating that these symptoms affect a large portion of the studied population. These body areas present a higher incidence of pain or discomfort, which indicates that many students experience these types of problems frequently. The duration of the episodes varies, with some students reporting occasional discomfort, while others mention that the discomfort persists for several hours a day.

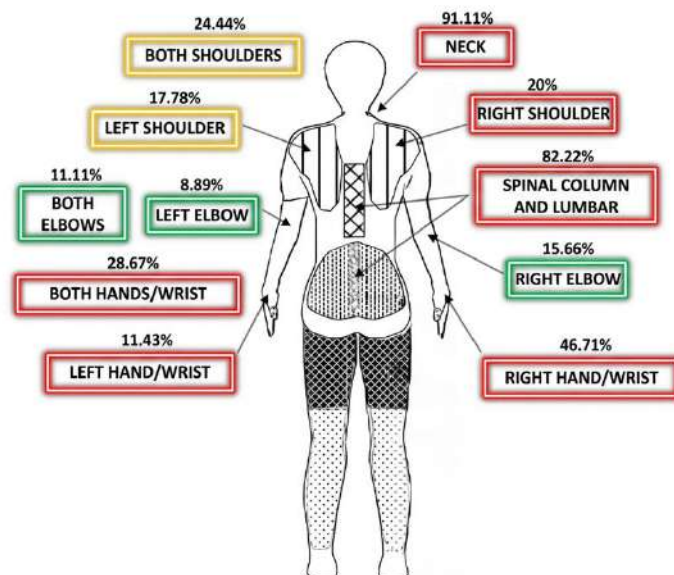


Figure 1. Symptomatology

Figure 2 reveals that 80% of the students have suffered neck pain in the last 7 days, while the dorsal or lumbar area and the shoulder show percentages of 76% and 58%, respectively.

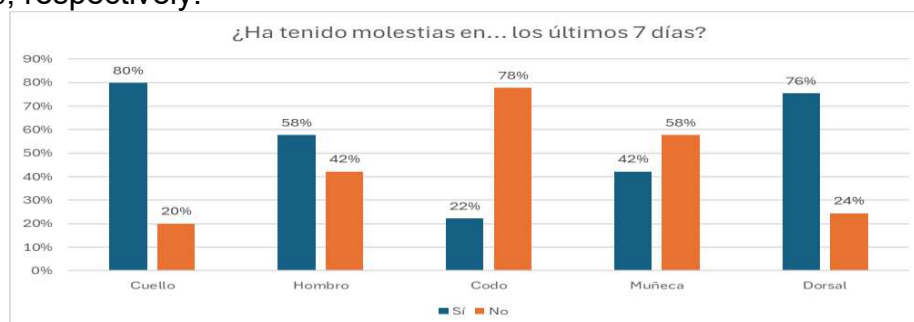


Figure 2. Neck, shoulder, elbow, wrist, or dorsal discomfort in the last 7 days.

2. OBJECTIVES

To evaluate the ergonomic and psychosocial risk to which Architecture students at ITSON University are exposed through ergonomic evaluation methods in order to establish a corrective proposal.

3. METHODOLOGY

3.1 Study Subject

Students enrolled in the Architecture program at ITSON Navojoa campus.

3.2 Procedure

1. Contextualize the Architecture program and its activities by semester.
2. Record the postures.
3. Evaluate the postures using the RULA method.
4. Evaluate the mental workload of the different students.
5. Develop an improvement proposal.

3.3 Materials

For the development of this project, the following elements were required:

- RULA field sheet format
- Survey based on NOM-STPS-035-2018
- Camera
- Magic Poser software

4. RESULTS

The Architecture program has been offered for approximately four years at the Instituto Tecnológico de Sonora (ITSON) south campus. As time has passed, community interest in this program has increased, making it one of the preferred programs among students, with approximately 240 students enrolled across different semesters.

ITSON has taken the initiative to adapt some of its classrooms and laboratories with specialized equipment such as drafting tables, desks, and computers. This equipment is used to carry out academic activities throughout the program, beginning with technical drawing, continuing with 2D and 3D design, and concluding with rendered structures and scale models.

Architecture students have access to different areas to carry out their academic activities, which include:

- **Architecture Laboratory:** This space contains drafting tables used by students during class hours.
- **Library:** In this space students carry out activities outside of class, either working on their laptops or on physical plans.
- **CIT (Technological Innovation Center):** In this area, electronic plans are developed with the help of the computers available there.

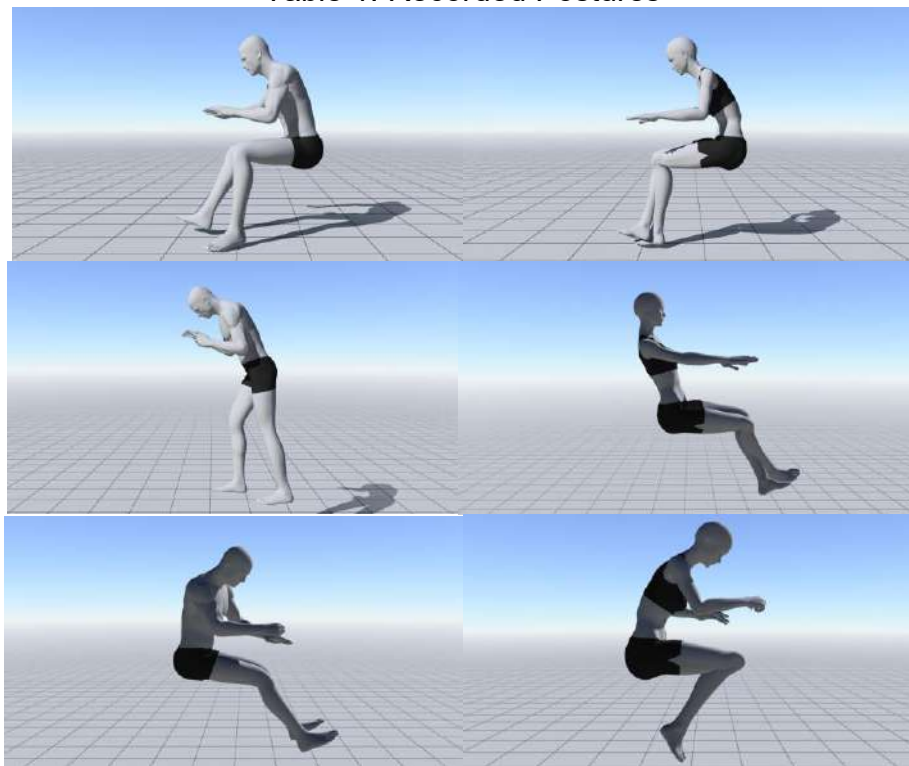
These areas were considered within the study, recording the postures of students while they were working in any of these spaces.

4.1 Recording Postures

The postures of 14 students (6 in the library, 4 at drafting tables, and 4 in the CIT) were recorded through a video capturing 180 degrees of the student, including the rear and lateral views, allowing correct observation of posture.

In order to protect the privacy of the studied community, the postures were recreated in specialized software for modeling human bodies and their postures. The following postures were recorded.

Table 1. Recorded Postures



4.2 Evaluation of Postures Using the RULA Method

The recorded postures were evaluated using the Rapid Upper Limb Assessment (RULA) method, which according to Rodríguez Sáez (2013) “evaluates postural load throughout the entire body, paying special attention to the neck, trunk, shoulders, arms, and wrists,” also considering the time during which the posture is maintained, the required force, and its repetition. It should be noted that this tool must be applied to each side of the subject’s body under evaluation. To support this method, a standardized assessment form was used, which includes all body regions to be evaluated and the corresponding evaluation criteria. This assessment is based on a system of angles and weighted scores assigned to each posture. Following the

postural assessment, an Action Level Factor is obtained as the final outcome; depending on its value, it corresponds to a specific risk level. In this manner, the subjects included in the study were evaluated, and the results of the postural load were obtained (see Table 2).

Table 2. RULA Results

Posture	L Result (Left)	R Result(Right)
Subject 1 in the library	5	5
Subject 2 in the library	5	5
Subject 3 in the library	5	6
Subject 4 in the library	5	5
Subject 5 in the library	6	6
Subject 6 in the library	5	6
Subject 1 at draftingtables	7	6
Subject 2 at draftingtables	6	6
Subject 3 at draftingtables	6	6
Subject 4 at draftingtables	4	4
Subject 1 in CIT	5	6
Subject 2 in CIT	5	5
Subject 3 in CIT	4	6
Subject 4 in CIT	4	6

The analysis of Table 2 indicates that the majority of students obtained scores that require ergonomic attention (greater than 4). This highlights the importance of implementing corrective measures in work areas in order to reduce the risks associated with inadequate posture. Additionally, it presents a significant ergonomic problem, as more individuals are classified at high risk levels (6). This may be related to the specific tasks performed on that side or to highly forced postures. Therefore, it would be necessary to prioritize interventions in this area in order to reduce potential risks.

4.3 Mental Workload Assessment

On the other hand, in order to analyze the mental workload experienced by the students, an instrument was applied to 102 students, consisting of 23 questions divided into six sections. These questions were related to psychosocial aspects in their different work environments (class workshop, laboratory, library, or at home). The results are presented below.

The gender distribution among the surveyed students indicates that there were 63 female students, 38 male students, and 1 student who preferred not to disclose their gender.

1. Identification of Psychosocial Risk Factors

In Section 1, significant information regarding students' well-being was identified. A notable 96.07% of students reported experiencing stress due to demanding deadlines. In addition, 93.13% of the students feel continuous pressure to achieve high levels of academic performance.

On the other hand, a concerning 17.64% of respondents reported experiencing situations of workplace violence or harassment, which may affect their emotional well-being. Furthermore, a high percentage (82.35%) indicated that long study hours negatively impact their mental health. Finally, 58.8% of the students feel they do not receive adequate feedback on their work, which may limit their academic development.

2. Working Conditions and Study Spaces

Regarding students' study conditions, it was observed that 28.43% of students do not have access to an adequate space for studying. In addition, 14.70% of students lack functional and ergonomic work equipment, which may affect their performance and comfort.

On the other hand, 11.76% of students do not have a space that facilitates interaction with classmates without generating noise, which may limit collaboration and group learning. Finally, 32.35% of students do not have a spatial layout that helps prevent back pain and academic fatigue.

3. Work Organization and Time Management

Section 3 includes questions related to work organization and time management that may affect students' academic activities. The results regarding time management among students show that 8.82% of the respondents do not organize their time effectively to avoid task overload.

In another question, 36.27% of the students indicated that they do not have sufficient time to rest during study sessions or while completing assignments. Additionally, 29.41% of the architecture students feel unable to ask for help when their workload becomes intense. Finally, 9.8% of the students do not establish clear priorities for managing their activities, which contributes to procrastination.

4. Communication and Support in the Academic Environment

The questions related to communication and support in the academic environment aim to understand how students feel about their interaction with professors and classmates, as well as the level of support they receive during their educational process.

The perception of architecture students regarding communication and support in their academic environment shows that 8.8% of the students feel they cannot express problems related to their academic workload. In addition, 7.8% reported that they do not receive constructive feedback from their instructors. Finally, 29.4% of the

students indicated that they do not have access to emotional support when they need it.

5. Prevention and Well-Being Strategies

These questions aim to evaluate how students perceive and manage their emotional and physical well-being in the academic context. The results show that 20.5% of the surveyed students do not take active breaks to prevent fatigue during long study sessions. In addition, 34.31% of the students do not practice stress-management techniques, such as meditation or physical exercise.

On the other hand, 24.5% of the respondents do not maintain an active social life outside the institution. Finally, 39.2% of the architecture students do not get enough sleep to maintain an adequate level of concentration and mental health. These findings highlight the need to promote healthy habits and well-being strategies among students in order to improve their academic performance and quality of life.

6. Evaluation and Continuous Monitoring

These questions regarding evaluation and continuous monitoring—aimed at adjusting objectives and preventing burnout—are essential for understanding how students perceive their academic workload and which strategies they consider necessary to manage their time and effort effectively.

The results indicate that 3.9% of the students do not periodically review their academic workload or adjust their goals to prevent burnout. In addition, 13.7% of the respondents reported that they do not receive evaluations of the academic environment that would allow them to identify areas for improvement. Finally, another 13.7% of the students reported that they do not have the opportunity to participate in surveys aimed at identifying psychosocial risks within their academic environment.

These findings highlight the need to implement more effective evaluation and feedback mechanisms, as well as to encourage student participation in initiatives that promote a healthier academic environment and greater awareness of psychosocial risks.

4.4 Improvement Proposal

Based on the ergonomic analysis conducted among architecture students, the following improvement proposals are presented. These proposals are designed to optimize working and study conditions, promote postural health, and increase academic efficiency.

4.4.1 Renewal of seating at drafting tables

Replace the current seats with height-adjustable stools designed to facilitate mobility and reduce fatigue during prolonged work at drafting tables. This will allow greater

adaptability to the diversity of students' heights and body compositions, promoting proper posture and minimizing the risk of muscular discomfort or injury.

4.4.2 Furniture update in the library and the Technological Innovation Center (CIT)

Implement height-adjustable chairs in both areas, considering the anthropometric measurements of the studied population. These chairs will allow users to adopt a neutral posture, ensure that the feet rest completely on the floor, and reduce tension in the lumbar region.

4.4.3 Replacement or modification of drafting tables

Replace the current drafting tables with drawing tables adjustable in both height and tilt angle. This will not only allow students to work in ergonomic positions but will also promote greater flexibility in the use of these tables for different types of academic activities.

4.4.4 Use of laptop stands

Incorporate adjustable laptop stands, which will facilitate proper screen positioning at eye level and reduce strain on the neck and back. These stands should include portable and easy-to-use features in order to optimize space and adapt to individual needs.

4.4.5 Training in correct posture

Implement workshops and training sessions for students focused on the importance of maintaining correct postures during study and work activities. These sessions should include practical techniques such as proper furniture adjustment, active breaks, and stretching exercises in order to promote healthy habits and prevent musculoskeletal disorders.

4.4.6 Healthy Life Program

Based on the findings obtained from the mental workload assessment, the following actions are proposed to improve academic conditions, reduce stress, and promote the overall well-being of architecture students:

Training in planning and prioritization techniques

Offer workshops that teach students time-management tools such as priority matrices, detailed academic calendars, and technological applications for task organization.

Reduction of simultaneous assignment workload

Coordinate assignment deadlines across different courses in order to avoid excessive accumulation of tasks during specific periods.

Workshops on relaxation and stress-management techniques

Incorporate regular sessions of meditation, mindfulness, and breathing exercises that allow students to learn how to manage pressure and balance their emotions.

Promotion of personal time

Respect non-academic schedules by reducing the demand for activities outside official class and assignment hours.

Periodic surveys

Maintain the application of questionnaires to evaluate mental workload and psychosocial factors, ensuring early identification of potential problems.

5. CONCLUSIONS

The ergonomic analysis conducted in the work areas of architecture students at ITSON Navojoa allowed the identification of significant risks across various physical and psychosocial dimensions. The results obtained through the RULA method and the mental workload assessment highlight critical areas that require priority attention in order to improve working and study conditions.

In conclusion, this project highlights the importance of addressing ergonomic and psychosocial risks comprehensively by implementing structural and educational changes that contribute to students' well-being and performance. The adoption of the proposed improvements will not only help prevent long-term health problems but also foster a more balanced and sustainable environment for academic development.

It is recommended to expand the study in order to determine the most appropriate type of seating for prolonged use at drafting tables, considering ergonomic and anthropometric criteria. Likewise, it is suggested to develop a functional and affordable laptop stand prototype that is accessible and practical. Additionally, the development of an adjustable drafting table model, both in height and tilt angle, is proposed by reusing an existing drafting table as a base, in order to evaluate its functionality and feasibility.

The findings obtained regarding psychosocial risk factors make it possible to understand how different variables influence students' mental workload, directly affecting their academic performance and overall well-being. These results highlight the complexity of the demands faced by students within their academic environment, as well as the multiple variables that determine their ability to effectively manage these requirements. Therefore, this study serves as a starting point for reflecting on the identified conditions, recognizing their impact, and taking concrete actions to address the needs that arise in this context, with the aim of improving academic conditions and their effect on students' overall well-being.

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ERGONOMIC EVALUATION OF THE MANUAL GRAIN FUMIGATION PROCESS IN SHIP HOLDS USING THE REBA METHOD

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Resumen La fumigación de granos en bodegas de buques constituye una actividad esencial para el control de plagas durante el almacenamiento y transporte de productos agrícolas. Sin embargo, esta labor implica la adopción de posturas forzadas, movimientos repetitivos y trabajo sobre superficies inestables que pueden generar riesgos ergonómicos significativos para los trabajadores.

El presente estudio tuvo como objetivo evaluar el nivel de riesgo postural asociado a la tarea de fumigación de grano mediante la aplicación del método REBA (Rapid Entire Body Assessment). La evaluación se realizó durante la ejecución real de la tarea en una bodega de buque cargada con maíz blanco. Se analizó la postura más representativa adoptada por el trabajador durante la aplicación de pastillas de fosfuro de aluminio.

Los resultados indicaron una puntuación REBA de 9, correspondiente a un nivel de riesgo alto y nivel de actuación 3, lo que sugiere la necesidad de implementar medidas correctivas en el corto plazo.

El estudio evidencia la importancia de integrar la evaluación ergonómica dentro de las actividades de fumigación, con el fin de prevenir trastornos musculoesqueléticos y mejorar las condiciones de trabajo en este tipo de operaciones.

Palabras clave: Ergonomía, REBA, fumigación de granos, riesgo postural, ergonomía ocupacional.

Relevancia para la ergonomía: Si bien las operaciones de fumigación suelen abordarse principalmente desde la perspectiva del riesgo químico, las exigencias físicas asociadas a la tarea pueden generar una carga significativa sobre el sistema musculoesquelético de los trabajadores.

Abstract: The fumigation of grain in ship holds is an essential activity for pest control during the storage and transport of agricultural products. However, this work involves adopting awkward postures, repetitive movements, and working on unstable surfaces, which can pose significant ergonomic risks for workers.

The objective of this study was to evaluate the level of postural risk associated with the task of grain fumigation using the REBA (Rapid Entire Body Assessment) method. The evaluation was carried out during the actual performance of the task in a ship's hold loaded with white corn. The most representative posture adopted by the worker during the application of aluminum phosphide tablets was analyzed.

The results indicated a REBA score of 9, corresponding to a high risk level and action level 3, suggesting the need to implement corrective measures in the short term.

The study highlights the importance of integrating ergonomic assessment into fumigation activities in order to prevent musculoskeletal disorders and improve working conditions in this type of operation.

Keywords. Ergonomía, REBA, fumigación de granos, riesgo postural, ergonomía ocupacional.

Relevance to Ergonomics: Although fumigation operations are usually approached primarily from the perspective of chemical risk, the physical demands associated with the task can place a significant burden on workers' musculoskeletal systems.

1. INTRODUCTION

Ergonomics is a multidisciplinary science focused on adapting work conditions, tools, and tasks to the physical and cognitive capabilities of human beings in order to improve safety, health, and overall work performance. One of the main objectives of ergonomics is the prevention of occupational injuries and the reduction of work-related musculoskeletal disorders (WMSDs), which represent one of the most common occupational health problems worldwide (Karwowski, 2006).

Work-related musculoskeletal disorders are associated with a wide range of occupational risk factors such as repetitive movements, awkward or sustained postures, forceful exertions, and inadequate workplace design. These factors can generate biomechanical overload in different parts of the body, particularly in the lower back, shoulders, neck, and upper limbs (Punnett & Wegman, 2004). Over time, continuous exposure to these conditions may lead to fatigue, discomfort, and chronic musculoskeletal injuries that affect both worker well-being and productivity.

In many industrial and agricultural activities, manual tasks continue to play a central role in operational processes. Among these activities, grain fumigation inside ship cargo holds represents an important operation aimed at preventing pest infestation during the storage and transportation of agricultural products. This task typically involves the manual distribution of fumigant tablets across the grain surface while the worker moves across the cargo hold.

Although fumigation procedures are generally analyzed from the perspective of chemical safety due to the hazardous nature of fumigants such as aluminum phosphide, the physical demands associated with the task are often overlooked. Workers performing fumigation activities frequently adopt awkward postures, including sustained trunk flexion, elevation of the upper limbs, and repetitive arm

movements while attempting to maintain balance on unstable surfaces composed of loose grain.

Working on unstable surfaces significantly increases physical effort because the worker must constantly adjust body posture to maintain stability and prevent falls. These adjustments may increase muscular effort and place additional strain on the musculoskeletal system (Dul & Weerdmeester, 2008). Furthermore, repetitive movements combined with awkward postures may accelerate the development of musculoskeletal disorders in exposed workers.

For this reason, ergonomic risk assessment is an essential tool for identifying and quantifying physical demands associated with specific work activities. Several ergonomic assessment methods have been developed to analyze body posture and evaluate biomechanical risk in occupational tasks.

One of the most widely used methods for postural evaluation is the Rapid Entire Body Assessment (REBA) method, developed by Hignett and McAtamney (2000). This method allows the systematic evaluation of body postures by analyzing different body segments such as the neck, trunk, legs, arms, forearms, and wrists. The REBA method assigns scores to each body segment based on its position and combines these scores to estimate the overall ergonomic risk level associated with a task.

The results obtained through REBA allow researchers and occupational safety professionals to classify the level of ergonomic risk and determine the urgency of corrective interventions aimed at reducing physical strain and preventing injuries.

Therefore, conducting ergonomic assessments in tasks such as grain fumigation is essential for identifying risk factors that may affect worker health. By applying ergonomic evaluation methods, it becomes possible to better understand the physical demands of the task and develop strategies to improve working conditions, reduce biomechanical stress, and prevent musculoskeletal injuries.

2. OBJECTIVES

General Objective

To evaluate the ergonomic risk associated with grain fumigation tasks performed in ship cargo holds using the REBA (Rapid Entire Body Assessment) method.

Specific Objectives

- To identify the main postures adopted by workers during the fumigation process.
- To analyze the biomechanical load on different body segments during the execution of the task.
- To determine the level of ergonomic risk associated with the observed working posture using the REBA method.
- To provide information that may support the development of preventive ergonomic measures to improve working conditions.

3. METHODOLOGY

3.1 Workplace Visit

A visit to the work area was conducted in order to observe the actual conditions under which the fumigation task is performed. Workplace visits are commonly used in ergonomic studies because they allow researchers to directly analyze the interaction between the worker, the task, and the work environment (Wilson & Corlett, 2005).

During the visit, the fumigation process inside the ship cargo hold was observed in order to understand the sequence of activities involved in the task. Special attention was given to the postures adopted by the worker, the movements performed during fumigant application, and the environmental conditions that could influence physical workload.

The observation revealed that the worker must walk across the grain surface while manually distributing fumigant tablets. The grain surface creates an unstable support base that requires constant adjustments in body posture to maintain balance. Additionally, the worker frequently bends the trunk forward while reaching the grain surface and elevates the arms to distribute the fumigant.

These observations allowed the identification of several potential ergonomic risk factors related to posture, movement repetition, and environmental conditions.

3.2 Risk Mapping of the Work Area

A risk mapping of the work area was conducted to identify the main ergonomic hazards present during the fumigation task. Risk mapping is a useful tool for identifying and visualizing potential hazards in a workplace and understanding how these hazards may affect worker safety and health (Bishop & Corlett, 2005).

The analysis considered several factors that may contribute to ergonomic risk, including:

- awkward body postures
- repetitive movements
- unstable support surfaces
- physical effort required to perform the task
- environmental conditions inside the cargo hold

The mapping process allowed the identification of areas where the worker is exposed to increased physical demands during fumigation activities.

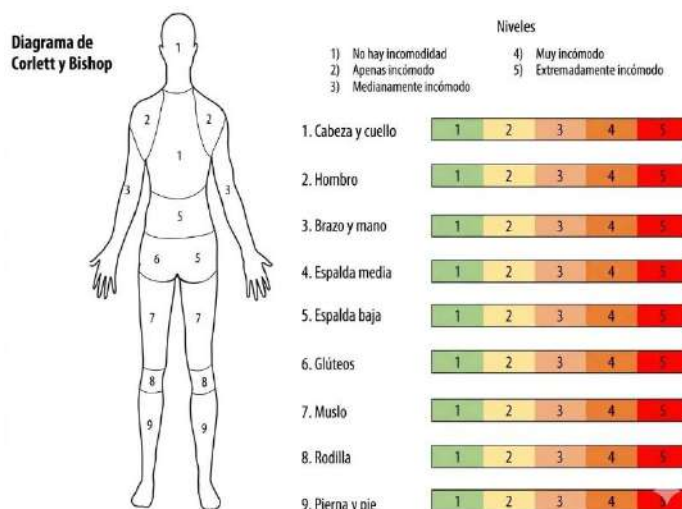


Figure 1. Corlette and Bishop's diagram

3.3 Worker Interview

In order to complement the observational analysis, a semi-structured interview was conducted with the worker performing the fumigation task. Worker interviews are commonly used in ergonomic studies because they provide valuable information regarding perceived physical effort, fatigue, and discomfort experienced during work activities (Dul & Weerdmeester, 2008).

The interview included the following questions:

1. How long have you been working in the fumigation position?
2. How many hours per day do you usually perform fumigation tasks?
3. Do you consider the fumigation task physically demanding?
4. Which parts of your body feel the most physical strain during the fumigation process?
5. Do you experience fatigue or discomfort after performing this task?
6. At what moment of the workday do you feel the greatest physical fatigue?
7. Do you think that the grain surface affects your balance while working?
8. How would you rate the physical effort required to perform fumigation activities?
 - Low
 - Moderate
 - High
9. Do you consider that the movements performed during fumigation are repetitive?
 - Yes
 - No
10. What improvements do you think could make this task safer or easier to perform?

The information obtained from the interview helped to identify the worker's perception of the physical demands associated with the task and provided additional context for interpreting the ergonomic evaluation results.

3.4 Ergonomic Assessment Method

3.4.1 Description of the Fumigation Work Process and Work Cycle

The fumigation process evaluated in this study is carried out inside the cargo hold of a ship containing stored grain. The objective of the activity is to distribute aluminum phosphide tablets within the grain mass in order to control and prevent pest infestation during storage and maritime transport.

The fumigation procedure is performed manually using a tubular applicator designed to introduce fumigant tablets deep into the grain. The task requires the worker to move across the surface of the grain while repeatedly inserting the applicator into the grain mass and releasing the fumigant tablets.

Because the work is performed directly on the grain surface, the operator must maintain balance on an unstable support surface while simultaneously manipulating the applicator and handling the fumigant tablets. These working conditions require continuous physical effort and the adoption of several non-neutral body postures.

The work cycle observed during the fumigation process can be described as follows.

Step 1. Access to the grain surface

The process begins when the operator enters the ship cargo hold and climbs onto the surface of the stored grain. The grain surface acts as an unstable support base due to the loose nature of the material. As a result, the worker must constantly adjust body posture in order to maintain balance while moving across the cargo hold.

During this phase, the operator visually inspects the area to determine the distribution pattern for the fumigation tablets.

Step 2. Delivery of fumigation equipment

Once positioned on the grain surface, the operator receives the necessary fumigation equipment. This includes the fumigation applicator, which is a tubular device designed to introduce fumigant tablets into the grain mass.

In addition, the worker receives a bottle containing aluminum phosphide tablets, which serve as the fumigation agent. These tablets release phosphine gas when exposed to moisture within the grain, which acts to eliminate pests.

Step 3. Loading the applicator with fumigant tablets

The operator opens the bottle containing the aluminum phosphide tablets and manually places a portion of the tablets into the tip of the applicator.

This step requires precise handling of the tablets and careful manipulation of the applicator. Once the applicator has been loaded with the appropriate amount of fumigant tablets, the operator closes the bottle and places it aside in a safe location on the grain surface.

Step 4. Insertion of the applicator into the grain

After loading the applicator, the worker holds the device with both hands and inserts it vertically into the grain mass.

The operator pushes the applicator downward until their hands reach the grain surface, ensuring that the device penetrates as deeply as possible into the grain. This action allows the fumigant tablets to be placed deep within the grain mass, which improves the effectiveness of the fumigation process.

During this step, the worker often adopts a forward trunk flexion posture while exerting downward force on the applicator.

Step 5. Release of fumigant tablets

Once the applicator has reached the desired depth, the operator begins to withdraw the device from the grain.

While removing the applicator, the worker lightly strikes or taps the tube in order to release any tablets that may remain trapped inside the applicator. This action ensures that the fumigant tablets are properly released into the grain.

Step 6. Withdrawal of the applicator

After the tablets have been released, the worker completely removes the applicator from the grain.

This movement requires the operator to lift the applicator vertically while maintaining balance on the grain surface. In some cases, the worker must slightly adjust their stance in order to stabilize the body during this movement.

Step 7. Movement to the next fumigation point

Once the applicator has been removed, the operator advances approximately five steps across the grain surface in order to reach the next fumigation point.

The process is then repeated following the same sequence: loading the applicator, inserting it into the grain, releasing the tablets, and moving to the next position.

This cycle continues until the fumigation tablets have been distributed across the entire cargo hold.

The ergonomic evaluation was carried out using the **Rapid Entire Body Assessment (REBA)** method, which allows the analysis of body posture and estimation of musculoskeletal risk associated with work activities.

The assessment focused on the most representative and unfavorable posture observed during the fumigation process. The analysis considered the following body segments:

Group A

- Neck posture
- Trunk posture
- Leg position

Group B

- Upper arm position
- Forearm position
- Wrist posture

In addition, activity factors such as **repetition, static posture, and force exertion** were considered. The evaluation was performed on one side of the body because the movements and postures were observed to be symmetrical.

The collected postural information was used to calculate the final REBA score, which determines the level of ergonomic risk and the urgency of intervention.



Figure 2. Work posture observed during fumigation task.

Posture adopted by the worker during the fumigation of grain inside the ship cargo hold. The task requires forward trunk flexion and arm elevation while maintaining balance on an unstable grain surface.

Table 1. Results of the REBA methodology

Application of REBA method			
Body Segment	Observed posture	REBA score	Description
Group A: Neck	Moderate forward flexion	1	Worker bends neck while applying fumigation tablets
Group A: Trunk	Forward flexion (20 ° - 60°)	2	Trunk bending required to reach the grain surface

Group A: Legs	Unstable support on loose grain	1	Worker maintains balance on unstable grain surface
Group B: Upper arm	Arm elevation (45 ° - 90°)	2	Arm raised during tablet distribution
Group B: Forearm	Flexion between 60 ° - 100°	1	Arm position during fumigant handling
Group B: Wrist	Slight deviation	0	Wrist adjusts during manipulation of tablets
Group B: Coupling	Acceptable grip	0	Handling of fumigation tablets
Activity	Repetitive movements and sustained posture	+2	Continuous application of fumigant tablets

Equations used in this study correspond to the scoring procedure of the Rapid Entire Body Assessment (REBA) method. The REBA method evaluates the posture of different body segments and combines these scores to determine the overall ergonomic risk associated with a specific task (Hignett & McAtamney, 2000).

The calculation of the final REBA score is based on the combination of the scores obtained from Group A (neck, trunk, and legs) and Group B (upper arms, forearms, and wrists), including adjustments related to activity conditions such as repetition and static posture.

The first step in the evaluation consists of calculating the Group A score, which considers the posture of the neck, trunk, and legs:

$$A = \text{Neck} + \text{Trunk} + \text{Legs}$$

Where:

Neck = posture score assigned to neck position

Trunk = posture score assigned to trunk position

Legs = posture score assigned to leg support

The second step corresponds to calculating the Group B score, which evaluates the posture of the upper limbs:

$$B = \text{Upper Arm} + \text{Forearm} + \text{Wrist} + \text{Coupling}$$

Where:

Upper Arm = posture score assigned to the upper arm

Forearm = posture score assigned to the forearm

Wrist = posture score assigned to wrist position

Coupling = quality of grip during task execution

Finally, the overall REBA score is obtained by combining the scores of Groups A and B, including the adjustment factor for activity conditions:

$$\text{REBA} = A + B + \text{Activity}$$

Where:

A = Score obtained from Group A

B = Score obtained from Group B

Activity = adjustment factor for repetition and static posture

Based on the values obtained from the ergonomic evaluation of the fumigation task, the following scores were determined:

Group A score:

$$A = 4$$

Group B score:

$$B = 3$$

Activity adjustment factor:

$$\text{Activity} = 2$$

Substituting these values into the REBA calculation:

$$\text{REBA} = 4 + 3 + 2 = 9$$

According to the REBA classification scale proposed by Hignett and McAtamney (2000), a score of 9 corresponds to a high ergonomic risk level, indicating that corrective actions should be implemented as soon as possible.

4. RESULTS

4.1 Workplace visit to the fumigation area

As a result of the visits conducted to the ship cargo hold where the fumigation operation takes place, direct observations of the fumigation process were obtained.

These observations allowed the identification of the main body movements, postures adopted by the worker, the sequence of the work cycle, and the repetitive nature of the fumigation task.

During the observation period, the operator was monitored while performing the fumigation activity using the applicator and aluminum phosphide tablets. The working conditions inside the cargo hold were also analyzed, including the unstable grain surface and the spatial conditions where the task is carried out.

The observations made it possible to identify the body segments most involved in the task and the ergonomic demands associated with the fumigation process.

4.1.1 Body segments involved in the fumigation task

Trunk

Repeated forward trunk flexion while inserting the applicator into the grain mass.
Trunk stabilization while applying downward force to the applicator.
Occasional trunk rotation when moving to the next fumigation point.

Upper limbs

Repeated elevation of the arms during the manipulation of the applicator.
Sustained arm posture while pushing the applicator into the grain.
Arm movements while removing the applicator from the grain mass.

Neck

Slight neck flexion while observing the insertion of the applicator into the grain.
Neck stabilization during the application process.

Lower limbs

Continuous balance adjustments while standing on the grain surface.
Repetitive walking movements while moving between fumigation points.

4.1.2 Observed postures

During the fumigation activity, several non-neutral postures were identified that increase the biomechanical load on the worker.

Sustained forward trunk flexion during the insertion of the applicator.
Elevation of the upper limbs while handling the fumigation equipment.
Neck flexion while visually monitoring the insertion of the applicator into the grain.
Continuous lower limb adjustments required to maintain balance on the unstable grain surface.

These postures may generate biomechanical stress mainly in the lumbar region, shoulders, and neck, especially when the activity is performed repeatedly for extended periods.

4.1.3 Work cycle and repetitiveness

The fumigation task follows a repetitive work cycle that consists of inserting the applicator into the grain mass, releasing fumigation tablets, removing the applicator, and moving to the next application point.

Each cycle involves coordinated movements of the trunk, upper limbs, neck, and lower limbs. The repeated insertion and removal of the applicator requires trunk flexion and arm movements, while maintaining stability on the grain surface.

Due to the repetitive nature of the process, the worker performs the same sequence of movements multiple times throughout the fumigation operation, which increases the ergonomic demands associated with the task.

4.1.4 Duration of the task

The fumigation operation is typically performed during a period of approximately three hours within an eight-hour workday.

During this time, the operator continuously repeats the fumigation cycle while moving across the cargo hold. The prolonged exposure to repetitive movements, awkward postures, and unstable working conditions increases the physical demands placed on the worker.

4.2 Risk mapping of the fumigation work area and operator interview

4.2.1 Ergonomic risk mapping

The ergonomic risk mapping conducted in the fumigation area allowed the identification of several factors that may contribute to physical strain during the fumigation task.

The analysis revealed that the greatest physical load is concentrated in the trunk and upper limbs, due to the repeated trunk flexion and arm elevation required during the insertion of the applicator into the grain.

Moderate physical demand was also identified in the neck, mainly due to the need to visually monitor the insertion of the applicator into the grain.

The lower limbs play an important role in maintaining balance and stability while standing on the grain surface, which represents an unstable support base.

Factors considered in the ergonomic risk mapping:

Awkward postures:

During the fumigation process, the worker frequently adopts a forward trunk flexion posture in order to insert the applicator into the grain mass.

Repetitive movements:

The fumigation cycle requires repeated insertion and removal of the applicator, generating repetitive movements involving the trunk and upper limbs.

Unstable support surface:

The loose grain inside the cargo hold creates an unstable working platform that requires continuous postural adjustments to maintain balance.

Manual handling of equipment:

The worker must continuously manipulate the fumigation applicator throughout the task, which requires coordinated movements of the upper limbs and trunk.

Physical workload:

The repeated application of force to insert the applicator into the grain increases the physical demands placed on the worker.

4.3 Results of the interview conducted with operators in the fumigation area

A semi-structured interview was conducted with five operators working in the fumigation area in order to obtain information regarding the physical demands of the task, perceived fatigue, and the ergonomic conditions under which fumigation activities are performed.

The interviewed workers reported having between three and five years of experience performing fumigation tasks, indicating that they are familiar with the work process and the physical demands associated with the activity. This level of experience suggests that their responses reflect consistent exposure to the working conditions present during fumigation operations.

According to the operators, fumigation tasks are typically performed for approximately three hours per day, during which workers repeatedly perform the fumigation cycle inside the ship cargo hold. This cycle involves loading the fumigation applicator with aluminum phosphide tablets, inserting the applicator into the grain mass, releasing the tablets, removing the applicator, and moving to the next application point.

The interview allowed the identification of the main ergonomic challenges perceived by the operators, including physical fatigue, repetitive movements, and the unstable working surface created by the grain.

4.3.1 Analysis of interview results

The results obtained from the interviews indicate that the operators perceive the fumigation task as physically demanding, mainly due to the repeated insertion of the applicator into the grain mass and the need to maintain balance while standing on the grain surface.

All interviewed operators reported that the fumigation task involves repetitive movements, since the same work cycle is repeated continuously while moving across the cargo hold.

Regarding physical strain, the operators identified the lower back, shoulders, and arms as the body regions most affected during the fumigation process. This perception is consistent with the postures observed during the task, which involve repeated trunk flexion and arm elevation.

Additionally, the operators reported that fatigue tends to appear toward the end of the fumigation activity, suggesting that the physical load accumulates as the task is repeated during the three-hour fumigation period.

Another important observation is related to the unstable grain surface, which the operators identified as a factor that affects balance and requires constant adjustments in body posture while performing the fumigation task.

Finally, the workers suggested that improvements in the design of the fumigation applicator or the use of mechanical assistance tools could help reduce the physical effort required during the activity. These suggestions highlight the importance of implementing ergonomic improvements to reduce physical workload and improve working conditions.

5. CONCLUSION

The ergonomic assessment conducted using the REBA method resulted in a final score of 9, which corresponds to a high ergonomic risk level and action level 3, indicating that corrective measures should be implemented in the short term. This result suggests that the fumigation task analyzed in this study exposes workers to significant biomechanical stress during its execution.

The elevated risk level can be explained by the combination of several ergonomic factors observed during the task, including sustained trunk flexion, elevation of the upper limbs, repetitive movements, and the need to maintain balance on an unstable surface composed of loose grain. These working conditions increase the physical demands placed on the musculoskeletal system, particularly affecting the lumbar region, shoulders, and neck.

From a preventive ergonomics perspective, maintaining this level of exposure over time could lead to the development of fatigue, persistent discomfort, and work-related musculoskeletal disorders. Therefore, the results highlight the importance of addressing ergonomic risks in fumigation activities, which are traditionally evaluated mainly from a chemical safety standpoint.

It is also important to emphasize that the observed postures are largely determined by the characteristics of the task and the work environment, rather than by individual worker behavior. For this reason, effective risk reduction should focus on improvements in task design, work organization, and ergonomic training, aiming to minimize physical strain and enhance worker safety during fumigation operations.

The ergonomic evaluation of the grain fumigation task performed inside a ship cargo hold using the REBA method revealed a high level of ergonomic risk, with a final score of 9 and an action level of 3. These results indicate that the task exposes workers to significant biomechanical demands that may increase the likelihood of developing work-related musculoskeletal disorders.

The main contributing factors to this risk include sustained trunk flexion, elevation of the upper limbs, repetitive movements, and the unstable support surface formed by loose grain. Together, these conditions generate considerable physical strain on the musculoskeletal system, particularly affecting the lower back, shoulders, and neck.

The findings highlight the importance of incorporating ergonomic assessments into fumigation operations, which are commonly evaluated mainly from the perspective of chemical hazards. Addressing ergonomic risks in these activities is essential to improve working conditions and reduce the potential for musculoskeletal injuries.

Therefore, it is recommended to implement preventive measures such as improvements in task design, work organization, and ergonomic training in order to reduce physical workload and enhance worker safety during fumigation activities.

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ERGONOMIC EVALUATION OF MANUAL FILLING OF WATER BOTTLES BY MEANS OF REBA AND JSI

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Resumen: El llenado manual de botellas de agua en microempresas embotelladoras implica movimientos repetitivos, posturas forzadas y aplicación constante de fuerza, factores que incrementan el riesgo de desarrollar DTA en los trabajadores, principalmente en hombros, antebrazos y muñecas.

El presente artículo tuvo como objetivo evaluar ergonómicamente la operación de llenado manual de botellas de agua mediante los métodos REBA y JSI. Para ello se realizaron visitas para observación del área de trabajo, análisis del ciclo de operación, mapeo de riesgos mediante el diagrama de Corlett y Bishop y entrevistas a los operadores para identificar zonas de molestia y percepción del esfuerzo físico.

Los resultados mostraron un nivel de riesgo ergonómico muy alto, con una puntuación de 11 en REBA y un índice JSI de 81, evidenciando una alta exposición a movimientos repetitivos, posturas forzadas y esfuerzos constantes en la mano y muñeca.

Con base a estos resultados, se proponen mejoras como el ajuste de la altura de la válvula de llenado, la implementación de sistemas de accionamiento mediante pedal o interruptor y la instalación de soportes para las botellas, con el fin de reducir la carga física y prevenir lesiones en los operadores.

Palabras clave: REBA, JSI, DTA, repetitividad, Evaluación

Relevancia para la ergonomía: Este estudio nos permite conocer los riesgos asociados a la operación de llenado de botellas para generar un estudio con base científica sobre los riesgos actuales que enfrenta un operador en el trabajo manual del llenado de botellas de agua, asimismo, demuestra la utilidad de los métodos de evaluación para la detección temprana de riesgos ergonómicos y desarrollo de DTA, facilitando la toma de decisiones preventivas y al mismo tiempo ofrece propuestas de mejora apegada a la ingeniería industrial.

Abstract: The manual filling of water bottles in micro-bottling companies involves repetitive movements, awkward postures, and constant application of force, factors that increase the risk of workers developing MSDs, mainly in the shoulders,

forearms, and wrists. The objective of this article was to ergonomically evaluate the manual filling of water bottles using the REBA and JSI methods. To this end, visits were made to observe the work area, analyze the operation cycle, map risks using the Corlett and Bishop diagram, and interview operators to identify areas of discomfort and perception of physical effort. The results showed a very high level of ergonomic risk, with a REBA score of 11 and a JSI index of 81, evidencing high exposure to repetitive movements, forced postures, and constant strain on the hand and wrist. Based on these results, improvements are proposed, such as adjusting the height of the filling valve, implementing pedal or switch-operated systems, and installing bottle supports, in order to reduce physical strain and prevent injuries to operators.

Keywords. REBA, JSI, DTA, repeatability, Evaluation

Relevance to Ergonomics: This study allows us to understand the risks associated with bottle filling operations in order to generate a scientifically based study on the current risks faced by operators in the manual filling of water bottles. It also demonstrates the usefulness of assessment methods for the early detection of ergonomic risks and the development of MSDs, facilitating preventive decision-making while offering proposals for improvement in line with industrial engineering.

1. INTRODUCTION

Ergonomics is a science focused on adapting work to humans in order to prevent injuries, improve occupational health, and promote operational efficiency, especially in tasks that involve physical effort, awkward postures, and repetitive movements. Work-related musculoskeletal disorders represent one of the main occupational health problems globally, affecting the productivity and life quality of workers (Rojas et al., 2024). In light industry, specifically in the micro-enterprise segment of water bottling companies, many operations are still performed manually or semi-manually, requiring the repetitive handling of loads such as 1 L and 1 ½ L bottles. This type of task involves constant physical effort that can lead to biomechanical overload, fatigue, and the eventual onset of musculoskeletal disorders (Gallegos López, 2023). Manual material handling is documented as a significant ergonomic risk factor. Recent studies have identified that these activities are associated with elevated levels of risk for developing musculoskeletal discomfort or injuries in the back and upper extremities (Lady& Nuraeni, 2023). Ergonomic assessment of work tasks is a key tool for identifying and quantifying risk factors, providing a technical basis for intervening in demanding activities using methods such as REBA and JSI (Rojas et al., 2024). In this case, due to the physical demands of manually filling 1 L and 1 ½ L water bottles in a bottling plant, it is appropriate to apply ergonomic methods that allow us to understand the risks to which operators are exposed and propose improvement strategies (Villacrés, 2021).

2. OBJECTIVES

General objective: Evaluate the filling operation using two ergonomic methods in order to determine its impact on musculoskeletal health and exposure to developing CWD.

Specific objectives:

- Evaluate using the REBA method to determine the impact of the postures adopted during the filling operation on the trunk, neck, and legs.
- Evaluate the repetitiveness of the filling station operation using the JSI method to determine exposure to cumulative traumatic disorders in the distal part of the upper extremities.
- Propose improvement actions aimed at reducing ergonomic risk to help prevent musculoskeletal injuries in operators.

3. METHODOLOGY

3.1 Visit to the purification plant

Five visits were made to the water bottling plant over the course of one month in order to identify and understand the manual filling process.

- During this stage, the operator was directly observed while performing the task, recording postures, movements, use of limbs, cycle times, and repetitiveness of the operation.

3.2 Risk mapping of the bottle filling area and interviews with operators in the area.

Corlett and Bishop were used to map ergonomic risks in the water bottle filling area, considering factors such as forced postures, repetitive movements, work area height, manual handling of bottles, and vibration in the upper limbs.

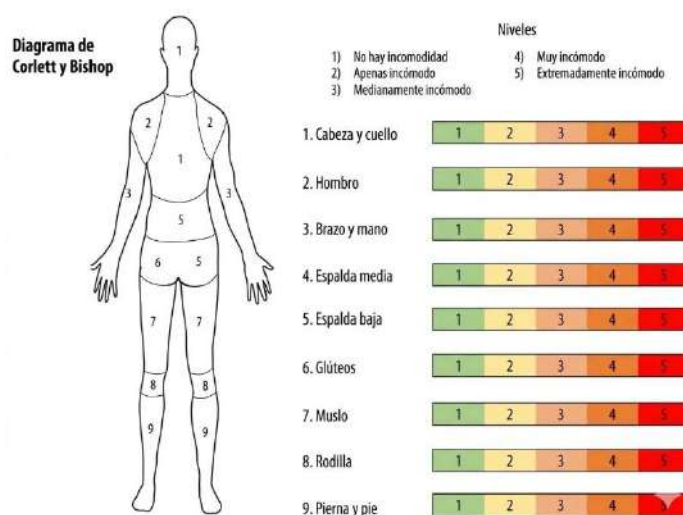


Figure 1. Corlett and Bishop diagram

- In addition, an interview was conducted with the water bottling area operator in order to identify discomfort in the limbs, areas of greatest fatigue, and the operator's personal perception of the physical effort associated with the workday.

Table 1. Survey for the manual filling area of water bottles

1. Length of service in the position: _____
2. How many hours do you work per day?
2-4 hrs 4-6 hrs 6-8 hrs - More than 8 hrs
3. Which hand do you use to control the water valve?
- Right - Left
4. Have you experienced any physical discomfort related to your work in the filling area?
- Yes - No
5. If yes, indicate the area of the body where you experience the most discomfort (you can select more than one):
- Hand - Wrist - Forearm

- Elbow
- Shoulder

6. When does this discomfort occur most frequently?

- Beginning of the workday
- Middle of the workday
- End of the workday

7. In which area of your body do you feel the most fatigue at the end of your shift? _____

8. How would you rate the physical effort required to manually fill bottles?

- Low
- Moderate
- High

9. Do you think that operating the valve requires constant manual force?

- Yes
- No

10. Do you feel that the movements are repeated many times during your workday?

- Yes
- No

11. How would you describe the pace of work when filling bottles?

- Slow
- Moderate
- Fast

12. Do you feel discomfort in your wrist when operating the water valve?

- Yes
- No

13. Do you find the position of your hand and wrist comfortable during operation?

- Yes
- No

Operator's opinion

14. Based on your experience, which part of the body do you consider to be most affected by this task?

15. Do you have any suggestions for improving working conditions in the filling area?

3.3 Application of the REBA and JSI methods

- The REBA method was applied to assess the operator's postural risk during the filling operation, considering the positions of the neck, trunk, and limbs, which made it possible to identify the risk level of the position and the need for ergonomic intervention.
- The JSI method was applied to determine the MSDs risk in the upper limbs, analyzing stress factors, repetitiveness, wrist posture, and work pace, which made it possible to calculate the JSI index and classify the risk level of the operation.

Table 2. Application and comparison of RBA and JSI

APPLICATION OF REBA AND JSI	
1. Simultaneously, hold a bottle with your left hand while holding the lever of the shut-off valve.	
REBA	JSI
In this operation, the neck undergoes an extension ranging from zero to twenty degrees, resulting in a score of two points for the neck. On the other hand, the arm adopts a posture greater than ninety degrees, which gives it a weighting of four points, plus one more point for elevation, resulting in a score of five points for the arm. 	In this operation, the right hand only makes initial contact with the lever, without overcoming significant resistance or maintaining the effort for a prolonged period of time. The action is brief and does not involve repetitive movements or forced postures, so the point of greatest demand for any of the JSI method factors is not identified in this phase. 
2. Position the filling bottle on the filling tube with your left hand while your right hand remains on the valve lever.	
REBA	JSI
In this operation, the right arm is in a position greater than ninety degrees and the left arm in a position ranging between forty-five and ninety degrees,	During this operation, the right hand remains on the lever in a position close to neutral, without significant deviations or forced movements. Although there is

which is considered a risk position according to the REBA method and, as previously established, is assigned a score of five.



a slight static load, this does not represent the most demanding point for any of the JSI method factors, so no factor is assigned to this operation.



3. Use your right hand to move the valve downwards, while your left hand holds the bottle until the bubbles rise to the neck of the bottle.

REBA

When the filling valve is activated, the right wrist undergoes a fifteen-degree extension, which, according to REBA, is assigned a weighting of three points. Meanwhile, the right arm remains at an angle of more than ninety degrees and the neck remains extended. This operation is one of the most ergonomically risky, as it involves forced postures for the neck, arm, and wrist, and the grip on the bottle is uneven, which raises the score for group one.



JSI

When operating the gate valve, the right hand overcomes the mechanical resistance of the system, generating a noticeable and repetitive effort that is classified as "somewhat hard." According to the JSI method tables, this condition corresponds to an value of IE=3, assigned to this operation because it represents the greatest manual force requirement of the cycle. Likewise, this phase presents the most critical posture of the right wrist, which adopts a significant deviation from the neutral position during the repetitive operation of the valve. According to the JSI posture table, this condition is classified as a significant deviation posture, assigning a value of HWP = 2. The concurrence of both factors makes this operation the critical point of the cycle from the JSI perspective. In relation to the duration of the effort, it is estimated that the active effort occupies between 80% and 100% of the cycle time, which, according to the JSI

	table, corresponds to a weighted value of $DE = 3$. 
4. With your right hand, return the valve lever to the zero position while the bubbles settle, keeping your left hand holding the bottle.	
REBA When returning the lever, the right wrist flexes more than fifteen degrees while the arm remains in a position exceeding ninety degrees, causing accumulated fatigue in the arm, while the left arm holds a bottle weighing up to 1,500 grams. The factors for the arm, wrist, and neck remain the same as in the previous movement. 	JSI The lever returns at a fast pace, dictated by the filling process, which requires the right hand to perform the movement quickly and continuously. According to the JSI method table, a fast working speed corresponds to a value of $SW = 1.5$, which is assigned to this operation as it represents the fastest pace imposed by the cycle. 
5. Repeat steps 3 and 4 for short periods until the bottle is covered with water (approximately 16 repetitions in 8 seconds).	
REBA The repetitive movements involved in this operation entail constant extension and flexion of the wrist, concentrating	JSI This operation involves the highest frequency of right-hand movements.

117 movements in 96 seconds, while keeping both arms in a forced static position, constituting a risk factor for musculoskeletal disorders.	Temporal analysis made it possible to determine: $EM = \frac{160}{1.36} = 117.64$ According to the JSI method table, a frequency greater than 117 efforts per minute and 36 seconds is classified as very high, assigning a value of EM = 3.
6. Move the bottle from your left hand to your right hand.	
REBA	JSI
In this operation, the arms remain in a forced position and, although there is no repetitive movement, fatigue builds up because the weight is significant considering the height at which the transition is made.	Although in this operation the right hand handles most of the load during the cycle, the effort is brief and does not exceed the demands already considered in other factors, so no additional factor is assigned using this method.
7. With your right hand, place the bottle on the right side of the bar, while picking up an empty bottle with your left hand.	
REBA	JSI
In this operation, the trunk performs a slight twist to position the bottle in place, which, according to REBA, adds one point to the trunk's weighting, which was two points for the flexion and extension of the trunk during the process. 	The work cycle described requires a working day of between 4 and 8 hours. According to the JSI method tables, this daily duration corresponds to a weighted value of DD = 1, which is assigned in this operation. 

3.4 Analysis of results

The results obtained from applying the REBA and JSI methods were analyzed together, allowing us to identify the level of ergonomic risk of the water bottle filling station and the most affected body parts.

3.5 Proposals for improvement based on the results

Based on the risk levels identified and the results analyzed, improvement proposals were developed focused on reducing the ergonomic risk of the filling station to improve conditions of forced postures and reduce the repetitiveness of the task, with the aim of preventing and reducing musculoskeletal injuries and occupational accidents.

4. RESULTS

4.1 Visit to the purification plant

As a result of visits to the purification plant, direct records were obtained of the manual bottle filling process, allowing the movements, postures, use of limbs, cycle times, and repetitiveness of the task to be identified.

4.1.1 Movements identified in the upper limbs

Right hand:

- Repetitive flexion and extension of the wrist when operating the valve
- Lateral deviation of the wrist during opening and closing
- Left hand
- Grasping and static holding movements of the bottle during filling

4.1.2 Postures observed

- Non-neutral posture of the right wrist when operating the valve
- Pronounced flexion and lateral deviation of the wrist at the moment of greatest demand
- Static posture of the left hand while holding the bottle
- Asymmetrical use of the upper limbs, with greater load on the right hand

4.1.3 Cycle time and repetitiveness

The cycle time of the manual filling process is short and constant for each bottle. Approximately 16 valve actuations were recorded in an 8-second period during the filling of each bottle, resulting in a high frequency of repetitive movements in the right wrist.

4.1.4 Task duration

The manual bottle filling operation is part of a working day of between 4 and 8 hours, during which the operator constantly performs the same sequence of movements.

4.2 Risk mapping of the bottle filling area and interviews with operators in the area.

4.2.1 Ergonomic risk mapping

The Corlett and Bishop diagram applied to the manual bottling area shows that the main area of discomfort is in the shoulders, where workers report a high level of discomfort. This suggests that the activities performed place a greater strain on this part of the body, probably due to the position of the arms during the operation.

Moderate discomfort is observed in the arms and hands, indicating fatigue due to repetitive use. In contrast, the back, legs, and feet show low or no levels of discomfort, so they do not represent a critical area in the activity analyzed.

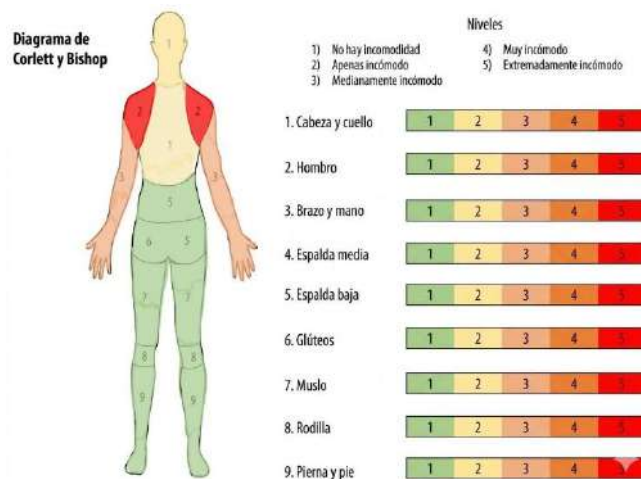


Figure 2. Corlett and Bishop diagram

Factors considered in the mapping

Forced postures:

When operating the water valve, the right wrist adopts a non-neutral posture, characterized by pronounced flexion and lateral deviation, which is repeated throughout the filling process.

Repetitive movements:

Repetitive movements of flexion and extension of the right wrist were identified, associated with the opening and closing of the valve, which are performed multiple times during the filling of each bottle.

Height of the work area:

The height of the filling area forces the operator to adjust the position of the arm and wrist to operate the valve and hold the bottle, favoring forced postures of the right upper limb.

Manual handling of bottles:

The process involves continuous manual handling of bottles, including repeated movements of grasping, holding, and placing during each work cycle.

Vibration in the upper limbs:

During repetitive valve operation, slight vibration was detected in the right hand, generated by the opening and closing mechanism.

4.2.2 Results of the interview with operators in the area**1. Length of service in the position**

Respuestas

6 años
4 años
3 años
2 años
1 año

Figure 3. Result 1

The results show that workers have been employed for between 1 and 6 years, indicating that staff have significant experience in the position.

This suggests that the discomfort and perceptions reported in subsequent questions do not correspond to new staff in the process of adaptation, but rather to workers with sufficient experience to understand the real demands of the position.

2. How many hours is your workday?

2-4 hrs	0
4-6 hrs	3
6-8 hrs	1
Mas de 8 hrs	2

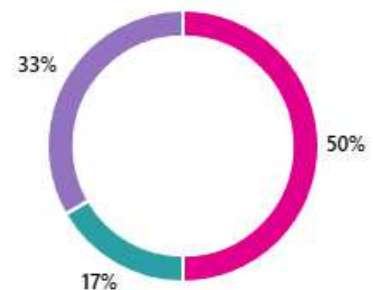


Figure 4. Result 2

Fifty percent of workers have a working day of 4 to 6 hours, indicating that part-time shifts predominate. However, 33% work more than 8 hours, which is a considerable percentage when analyzed from an ergonomic and physical load perspective, as long working days can increase the risk of fatigue and musculoskeletal discomfort. Only 17% work between 6 and 8 hours, and no short shifts of 2 to 4 hours were recorded, suggesting that work in this area generally requires moderate to prolonged exposure time.

3. Dominant hand for controlling the water shut-off valve?



Figure 5. Result 3

83% of workers use their right hand to control the water valve, indicating the use of the right upper limb in performing the task. Only 17% use their left hand, so the risk analysis can focus primarily on the right upper limb as the critical area of study.

4. Have you experienced any physical discomfort related to your work in the filling area?



Figure 6. Result 4

100% of the workers surveyed reported experiencing physical discomfort related to their work in the filling area. This result is highly significant, as it shows that all staff experience some type of discomfort related to their work activity.

5. If yes, indicate the area of the body where you experience the most discomfort (you may select more than one):



Figure 7. Result 5

The results show that the area of the body that causes the most discomfort is the forearm, indicated by 6 workers, followed by the shoulder with 5 mentions. To a lesser extent, discomfort in the wrist was reported by 2 workers and in the hand by only 1, while no discomfort was reported in the elbow.

6. When do these symptoms most often occur?



Figure 8. Result 6

No worker reported discomfort at the start of the workday, suggesting that discomfort is not immediate but develops as the workday progresses. Fifty percent reported that discomfort appears halfway through the workday, and the other 50% at the end of the workday, indicating a direct relationship between the duration of occupational exposure and the onset of muscle fatigue.

7. In which area of your body do you feel the most fatigue at the end of your shift?

Respuestas
En en cuello y hombros
En el hombro derecho y el brazo
En los hombros y en cuello
En el brazo y los hombros
en los hombros
En los hombros

Figure 9. Result 7

Analysis of the responses shows that the area with the most fatigue at the end of the working day is the shoulders, as this region was mentioned in 100% of the responses. Some workers also reported fatigue in the arm and neck, suggesting that the physical load is not limited to one area, but involves the shoulder-arm-neck region, probably due to static postures, repetitive arm lifting, or continuous effort during valve control.

8. How would you rate the physical effort required to manually fill bottles?



Figure 10. Result 8

The results show that 50% of workers consider the physical effort required to be moderate, while the other 50% rate it as high. No worker perceives the effort as low. This indicates that the activity of manually filling bottles involves significant physical demands. The fact that all workers perceive it as moderate to high suggests

that the task requires constant application of force, repetitiveness, or postures that generate considerable muscle strain.

9. ¿Considera que el accionamiento de la válvula requiere fuerza manual constante?



Figure 11. Result 9

67% of workers believe that operating the valve requires constant manual force, while 33% believe the opposite. This result indicates that, for most staff, the task involves maintaining sustained force during operation.

10. Do you notice that movements are repeated many times during your workday?



Figure 12. Result 10

100% of workers indicated that the movements they perform during their workday are perceived as repetitive, which indicates that there is a higher probability of developing some type of WMSD.

11. How do you rate the pace of work during bottle filling?

Figure 13. Result 11

The results show that 83% of workers consider the pace of work to be fast, compared to 17% who perceive it as moderate. This indicates that bottle filling is carried out under high speed requirements, which can put greater pressure on workers to maintain productivity

12. Do you feel discomfort in your wrist when operating the water valve?

Figure 14. Result 12

The results show that 100% of the workers surveyed reported feeling discomfort in their wrist when operating the water valve, which shows that this area of the body is directly involved in performing the task. This result suggests that the movement required to operate the valve involves repetitive efforts or postures that generate tension in the wrist joint.

13. Do you find the position of your hand and wrist comfortable during the operation?

Figure 15. Result 13

The results show that 100% of workers consider the position of the hand and wrist during the operation to be uncomfortable, indicating that the task is performed in an unergonomic position. This suggests that operating the valve causes forced positions in the wrist, which can lead to discomfort and fatigue in this joint.

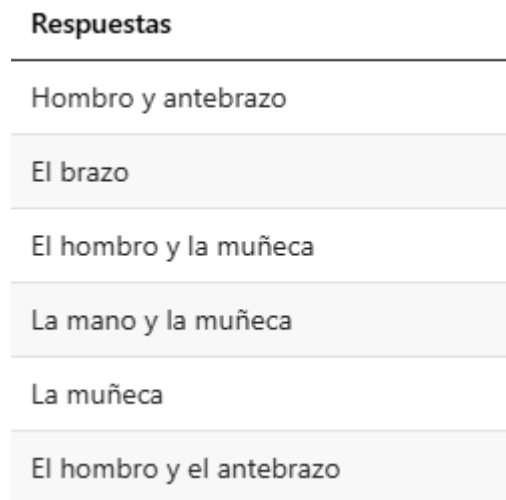
14. Based on your experience, which part of the body do you consider to be most affected by this task?

Figure 16. Result 14

The results show that the areas of the body most affected by the task are the shoulder, forearm, and wrist, as these were the parts most frequently mentioned by workers. This indicates that the activity places a greater physical strain on the upper limbs, which may be related to the manual effort and repetitive movements required to fill bottles.

15. Do you have any suggestions for improving working conditions in the filling area?

Respuestas

Que la llave de llenado este mas abajo u otro mecanismo que se pueda accionar con pedal.

Que el tubo de llenado llegue mas abajo para no tener necesidad de sostener la botella arriba.

Que la válvula de llenado no este tan alta

reducir la altura de la valvula y el tubo de llenado

Poner un sosten para la botella y bajar el tubo de llenado

cambiar la palanca de llenado por un boton o algo electronico

Figure 17. Result 15

The results show that most workers suggest modifying the height of the valve and filling tube, as well as incorporating mechanisms that facilitate operation, such as a pedal, button, or bottle holder. This indicates that the current conditions of the workstation require awkward postures and additional manual effort, so workers identify the need for ergonomic improvements in the design of the filling system to reduce the physical load during the task.

4.3 Application of the REBA and JSI methods

Table 3. resultss

REBA	JSI
The REBA assessment gives us a score of 11 points, which is classified as a very high risk that can cause operators to suffer musculoskeletal disorders in the upper limbs and strain in the lower spine, due to forced and static postures, as well as repetitive movements during long working hours. Immediate action is needed through proposals that eliminate or limit forced postures, reduce the repetitiveness of movements, and promote occupational	$JSI = IE \times DE \times EM \times HWP \times SW \times DD$ $JSI = 81$ The final JSI result was 81, indicating that the task evaluated is highly risky. This value is well above the range considered safe, meaning that the worker is exposed to repetitive movements, awkward postures, and constant strain on the hand and wrist. Consequently, there is a high probability of injury, making ergonomic improvements necessary.

health within the purified water bottling plant.	

4.4 Analysis of results

The job evaluation using the REBA method yielded a score of 11, which corresponds to a very high risk level. This result indicates that the postures adopted during bottle filling, especially in the trunk and upper limbs, represent a high probability of generating musculoskeletal disorders, mainly in the lower back and shoulders. The level obtained requires immediate intervention.

For its part, the JSI method presented an index of 81, classifying the task as highly risky for the hand and wrist. This value shows high exposure to repetitive movements and constant effort, which increases the likelihood of overuse injuries.

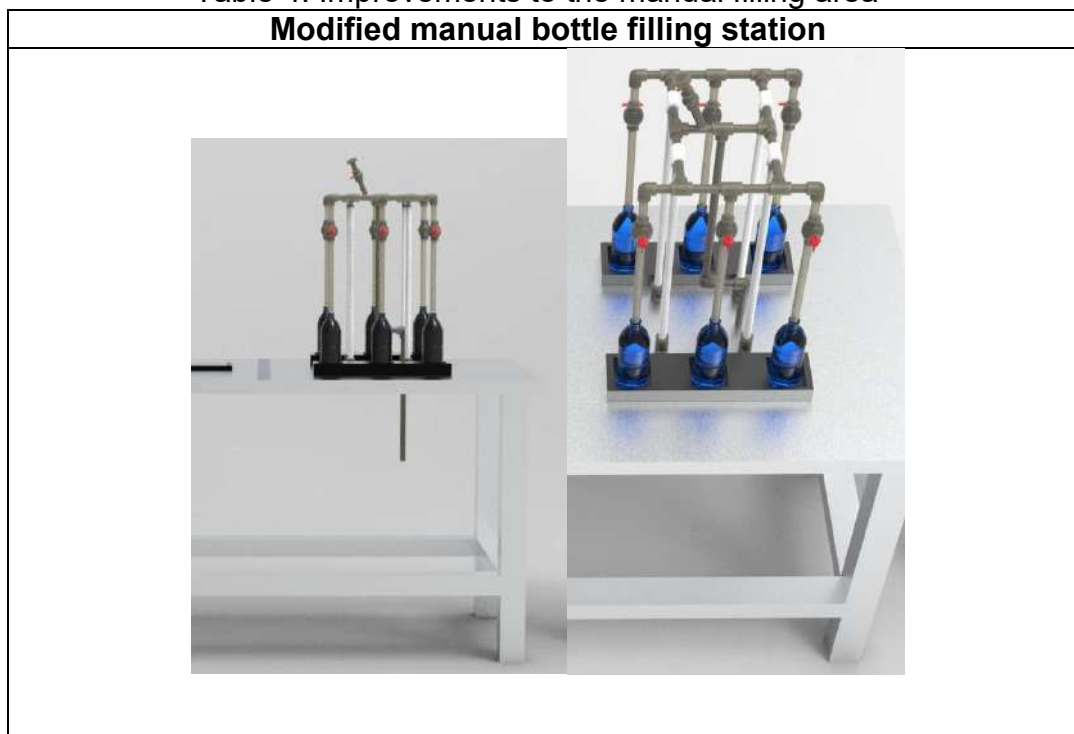
Overall, both methods agree that the position evaluated presents a high level of ergonomic risk, making it necessary to implement improvements in the design of the work area to reduce forced postures and repetitiveness.

4.5 Proposals for improvement based on the results

- During the assessment, it was identified that the height of the water shut-off valve is slightly too high, forcing an operator of average height to stretch as far as possible, causing fatigue in the shoulder and arm. It is therefore recommended that the height of the water shut-off valve be adjusted to prevent the operator from stretching and adopting an uncomfortable posture.
- It is proposed to modify the current water shut-off valve operating system to eliminate the manual function that requires repetitive wrist movements and constant application of force.
- It is proposed to install a support or base for the bottle during filling, so that the operator does not have to hold it manually throughout the process. This would help reduce static strain on the arm and forearm.

As an improvement, it is proposed to make the filling line independent, since ergonomically the bottle filling station requires specific measures to promote a working environment adapted to the conditions of the operators. This new filling station has three tubes that descend to the height of the table; this avoids having to lift the bottle to the height of the tube and having the arm at an angle close to ninety degrees. To avoid holding the bottles, a template is proposed that comprises a box in which the bottles fit perfectly, thus eliminating the need for support. As for the filling valve, it is proposed to replace it with a pressurized valve that can be operated by a switch at table height or by a pedal.

Table 4. Improvements to the manual filling area



5. CONCLUSION

The methods used to evaluate the task of manually filling bottles are relevant, appropriate, and accurate, as they provide specific and unambiguous information about the actual ergonomic conditions in which the operator is performing their work. In conclusion, the REBA and JSI method assessments reveal very high risk levels, which translate into discomfort in the upper limbs, particularly the shoulder, wrist, and hand; as well as strain on the trunk, neck, and legs, causing numbness, tingling, heaviness, and pain, which can result in short-term injuries to the upper and lower extremities and cumulative traumatic disorders due to repetitive movements. This type of study is of great relevance to the MSME sector in the sense that it gives prominence to occupational health in this sector, as it allows for the visualization of tasks that in the medium term generate risk situations for workers, thereby implying low productivity, efficiency, and quality in the performance of activities.

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ERGONOMIC EVALUATION OF A WORKSTATION IN THE GARMENT FACILITY USING THE REBA METHOD.

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RESUMEN: La industria de la confección se caracteriza por la ejecución de tareas repetitivas y la adopción de posturas estáticas y forzadas durante jornadas prolongadas, condiciones que incrementan el riesgo de desarrollar trastornos musculoesqueléticos. El presente estudio tuvo como objetivo evaluar ergonómicamente una estación de trabajo del área de confección mediante la aplicación del método REBA (Rapid Entire Body Assessment), con la finalidad de identificar el nivel de riesgo postural asociado a las actividades realizadas. La investigación se delimitó al análisis de una estación específica, sin contemplar la implementación de mejoras. La metodología consistió en la observación directa de los ciclos de trabajo, el registro fotográfico de las posturas adoptadas y la selección de aquella con mayor tiempo de exposición. Se evaluó el lado izquierdo del cuerpo por ser el de mayor exigencia durante la tarea. El método REBA permitió analizar de forma sistemática los segmentos corporales divididos en Grupo A (tronco, cuello y piernas) y Grupo B (brazo, antebrazo y muñeca), asignando puntuaciones con base en los ángulos de flexión, extensión, desviación y rotación observados. Los resultados indicaron una puntuación de 8 para el Grupo A y 4 para el Grupo B. Tras integrar las puntuaciones parciales, considerar la actividad muscular y descartar incremento por carga (menor a 5 kg), se obtuvo una puntuación final de 10 puntos. De acuerdo con la clasificación del método REBA, este valor corresponde a un nivel de riesgo alto, lo que implica la necesidad de intervención para reducir la exposición a factores de riesgo postural. Se identificó que la postura sedente prolongada (90 % de la jornada laboral), combinada con flexión de tronco mayor a 20°, flexión de cuello superior a 20° y desviaciones en muñeca, constituye el principal factor de riesgo ergonómico en la estación evaluada. Se concluye que el método REBA es una herramienta eficaz para la evaluación ergonómica en el sector textil, ya que

permite identificar de manera objetiva el nivel de riesgo postural y establecer el grado de actuación requerido. Los hallazgos obtenidos proporcionan un diagnóstico técnico que puede servir como base para futuras propuestas de mejora orientadas a la prevención de lesiones musculoesqueléticas y a la optimización de las condiciones de trabajo en el área de confección.

Palabras clave: Posturas, REBA, Estación, Confección, Evaluación.

Relevancia para la ergonomía: Al evaluar de manera sistemática los riesgos posturales en una estación de trabajo del área de confección mediante la aplicación del método REBA, permite identificar niveles de riesgo asociados a posturas forzadas y movimientos repetitivos, contribuyendo al diagnóstico ergonómico y a la prevención de trastornos musculoesqueléticos en entornos laborales. Su importancia radica en que proporciona evidencia aplicada en un contexto real de la industria textil, fortaleciendo la utilidad del método REBA como herramienta de evaluación. Asimismo, aporta una base para futuras investigaciones y para el desarrollo de estrategias de mejora en condiciones de trabajo, promoviendo la salud ocupacional y la eficiencia productiva.

ABSTRACT: The garment industry is characterized by repetitive tasks and the adoption of static and awkward postures for extended periods, conditions that increase the risk of developing musculoskeletal disorders. This study aimed to ergonomically evaluate a workstation in the garment area using the Rapid Entire Body Assessment (REBA) method to identify the level of postural risk associated with the activities performed. The research was limited to the analysis of a specific workstation, without considering the implementation of improvements. The methodology consisted of direct observation of work cycles, photographic documentation of the postures adopted, and selection of the posture with the longest exposure time. The left side of the body was evaluated because it is the side under the greatest strain during the task. The REBA method allowed for the systematic analysis of body segments divided into Group A (trunk, neck, and legs) and Group B (arm, forearm, and wrist), assigning scores based on the observed angles of flexion, extension, deviation, and rotation. The results indicated a score of 8 for Group A and 4 for Group B. After integrating the partial scores, considering muscle activity, and excluding any increase due to load (less than 5 kg), a final score of 10 points was obtained. According to the REBA method classification, this value corresponds to a high risk level, implying the need for intervention to reduce exposure to postural risk factors. Prolonged sitting (90% of the workday), combined with trunk flexion greater than 20°, neck flexion greater than 20°, and wrist deviations, was identified as the main ergonomic risk factor at the evaluated workstation. It is concluded that the REBA method is an effective tool for ergonomic assessment in the textile sector, as it allows for the objective identification of the level of postural risk and the establishment of the required level of intervention. The findings provide a technical diagnosis that can serve as a basis for future improvement proposals aimed at preventing musculoskeletal injuries and optimizing working conditions in the garment manufacturing area.

Keywords: Postures, REBA, Workstation, Garment Manufacturing, Assessment.

Relevance to Ergonomics: Systematically evaluating postural risks at a garment manufacturing workstation using the REBA method allows for the identification of risk levels associated with awkward postures and repetitive movements, contributing to ergonomic diagnosis and the prevention of musculoskeletal disorders in work environments. Its importance lies in providing applied evidence in a real-world context within the textile industry, reinforcing the usefulness of the REBA method as an assessment tool. Furthermore, it provides a foundation for future research and the development of strategies to improve working conditions, promoting occupational health and productivity.

1. INTRODUCTION

The fundamental purpose of occupational ergonomics is to adapt work to the physical and cognitive characteristics of human beings in order to prevent health problems and improve work performance. (Fernández, 2025).

Within the garment industry, activities are characterized by repetitive tasks, the adoption of static and awkward postures, and the continuous use of the upper extremities during prolonged workdays. These conditions increase the likelihood of developing discomfort and injuries in body regions such as the neck, back, shoulders, and wrists, affecting the worker's health and the efficiency of the production process. (Biomechanics Institute of Valencia, 2026).

The ergonomic evaluation of workstations allows for the identification and analysis of risk factors associated with the postures adopted during task execution. Among the most widely used postural assessment methods is the REBA (Rapid Entire Body Assessment) method, which facilitates the identification of ergonomic risk levels through the systematic analysis of whole-body postures, considering the load, grip type, and activity performed. (Diego-Mas, n.d.).

Mendoza (2025), in *Ergonomic Analysis in the Quality Inspection Area in the Mexicali Textile Industry*, analyzes ergonomic conditions in the textile industry, demonstrating that repetitive movements and prolonged static postures increase the risk of musculoskeletal disorders. His methodology is relevant as a reference for studies within the same sector.

Candelario (2025), in *Ergonomic Analysis of the Flower Bouquet Assembly Task*, evaluates manual assembly tasks with similar postural load conditions. Although developed in the floral industry, his results are applicable to the garment industry, highlighting the usefulness of the REBA method in various work contexts.

Taken together, these studies confirm that the REBA method is an effective tool for identifying postural risks, which is the foundation of this research.

This study will evaluate a workstation. The results obtained will provide an ergonomic diagnosis that will serve as a basis for decision-making aimed at preventing workplace injuries and improving working conditions.

2. OBJECTIVES.

2.1 General Objective

Evaluate a workstation in the garment area in order to identify the level of ergonomic risk associated with awkward postures, by applying the REBA method.

2.2 Specific objectives.

- Analyze the characteristics of the selected workstation in the clothing area.
- Document the work area and the postures adopted by the workers through photographic records.
- Apply the REBA method for the evaluation of observed work postures.
- Determine the score obtained and establish the level of risk and the corresponding degree of action.

3. DELIMITATION.

This project is limited exclusively to the ergonomic evaluation of a workstation located in the manufacturing area of the factory. The implementation or evaluation of corrective measures or proposals for improvement derived from the results obtained is not contemplated.

4. METHODOLOGY.

The REBA (Rapid Entire Body Assessment) method allows postural risk to be assessed by dividing the body into two main sets. Group A contemplates the analysis of the neck, trunk and legs, while Group B focuses on the upper extremities, considering arms, forearms and wrists (Figure 1). Each of these body segments is assessed through specific tables of the method, which makes it possible to obtain partial scores and, subsequently, global values for both groups (Diego-Mas, n.d.).



Figure 1. Member groups in REBA.

Source: <https://www.ergonautas.upv.es/metodos/reba/reba-ayuda.php>

4.1 Application of the method

The application of the REBA method is carried out through the following steps:

1. The work cycles are identified and the worker is observed. (Diego-Mas, n.d.).
2. The postures that will be the object of analysis are selected, prioritizing those that present a greater postural load.
3. The side of the body that will be evaluated is determined, either left or right. (Diego-Mas, n.d.).
4. The necessary angular data for the application of the method is obtained.
5. The scores corresponding to each body segment are assigned using the tables established by the method for each member evaluated (Diego-Mas, n.d.).
6. The partial scores and the final score of the method are calculated to establish the level of action required.
7. If risks are identified, corrective measures are defined.
8. Changes are implemented in the job or in the way the task is executed.
9. It is recommended to carry out a new evaluation using the REBA method to verify the effectiveness of the improvements introduced (Diego-Mas, n.d.).

5. RESULTS

The procedure followed for the application of the REBA method was developed as follows:

1. **Duty cycles**

The work cycles were long, lasting approximately 1 to 2 minutes per cycle.

2. **Position to be evaluated**

The position that represented the longest exposure time during the working day was selected. The posture evaluated was the sitting position, since the worker remains seated 90% of the working day to carry out his activities in the clothing area. (Figure 2)

3. **Determination of the side to evaluate**

Considering the layout of the work area and the way in which the worker executes his tasks, it was determined to evaluate the left side of the body, as it is the one that presents the greatest exposure during the observed activity.

4. **Determination of scores for each group.**

The body segments corresponding to the trunk, neck and legs (Group A), as well as the arm, forearm and wrist (Group B) were evaluated, according to the criteria established by the REBA method. For each segment, the corresponding scores were assigned based on the angles of flexion, extension and deviation observed during the execution of the task.

These scores allowed us to determine the intermediate score of the REBA method using the table corresponding to each member.



Figure 2. Evaluated postures of the seamstresses.

5.1 Group A results

When Group A (trunk, neck and legs) was evaluated, the results shown in Table 1 were obtained and the final score can be found in Table 2.

Table 1. Score awarded to Group A

Table 1: Score awarded to Group A		
Description	Scoring	On the other hand,
Trunk Scoring (Flexion >20° and <60°)	3	4
Modification of trunk scoring by lateral tilt and rotation.	+1	
Neck Score (Flexion >20°)	2	3
Modification of neck score by head rotation or lateral tilt	+1	
Leg Scoring (Sitting)	1	3
Leg scoring modification (Knee flexion >60°)	+2	
Final Score GROUP A = 8		

Table 2. Group A Score

	Cuello											
	1				2				3			
	Piernas				Piernas				Piernas			
Tronco	1	2	3	4	1	2	3	4	1	2	3	4
1	1	2	3	4	1	2	3	4	3	3	3	6
2	2	3	4	5	3	4	5	6	4	5	6	7
3	2	4	5	6	4	5	6	7	5	6	7	8
4	3	5	6	7	5	6	7	8	6	7	8	9
5	4	6	7	8	6	7	8	9	7	8	9	9

Note: Intersection scores Group A Source: <https://www.ergonautas.upv.es/metodos/reba/reba-ayuda.php>

5.2 Group B results

The score for **Group B** is obtained from the scores of each of the members that make it up (arm, forearm and wrist), the results obtained are shown in tables 3 and 4

Table 3. Score awarded from group B

Description	Scoring	On the other hand,
Arm Angle Score (Flexion >20°)	2	3
Modification of the angle score of the rotated or abducted arm.	+1	
Forearm Scoring (Flexion between 60° and 100°)	1	1
Wrist angle score (Flexion >0° and <15°)	1	2
Radial or ulnar twisting and deviation of the wrist.	+1	
Final score GROUP B = 4		

Table 4. Group B Score

	Antebrazo					
	1			2		
	Muñeca			Muñeca		
Brazo	1	2	3	1	2	3
1	1	2	3	1	2	3
2	1	3	4	2	3	4
3	3	4	5	4	5	5
4	4	5	5	5	6	7
5	6	7	8	7	8	8
6	7	8	8	8	9	9

Note: Intersection scores Group B Source: <https://www.ergonautas.upv.es/metodos/reba/reba-ayuda.php>

5.3 Partial and final scores of the method to determine the existence of risks and establish the Level of Action

5.3.1 Partial Scores.

The load handled or the force applied may modify the score assigned to Group A (trunk, neck and legs), but because the load does not exceed 5 kilograms in weight, the score was not increased. (Table 5)

Table 5. Increase in Group A score by load or forces exerted.

Carga o fuerza	Puntuación
Carga o fuerza menor de 5 Kg.	0
Carga o fuerza entre 5 y 10 Kg.	+1
Carga o fuerza mayor de 10 Kg.	+2

Note: Group A score increase by load or forces exerted. Source: <https://www.ergonautas.upv.es/metodos/reba/reba-ayuda.php>

5.3.2 Final results.

With the integration of the partial scores, the final score of the REBA method was obtained, which allowed the identification of the level of ergonomic risk present in the evaluated workstation. (Table 6)

Table 6. C-Score

Puntuación A	Puntuación B											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Tipo de actividad muscular	Puntuación
Una o más partes del cuerpo permanecen estáticas, por ejemplo soportadas durante más de 1 minuto	+1
Se producen movimientos repetitivos, por ejemplo repetidos más de 4 veces por minuto (excluyendo caminar)	+1
Se producen cambios de postura importantes o se adoptan posturas inestables	+1

5.3.3 Final Score

The final score obtained that allowed us to identify the level of performance is found in Table 9.

Table 9: Final score.

Scores	
Score A = 8	Score C= 9
Score B=4	
Increase in ScoreC= +1	FinalScore = 10

5.3.4 Performance level

Table 10 shows the Performance Levels according to the final score.

Table 10: Performance levels according to the final score obtained.

Puntuación	Nivel	Riesgo	Actuación
1	0	Inapreciable	No es necesaria actuación
2 o 3	1	Bajo	Puede ser necesaria la actuación.
4 a 7	2	Medio	Es necesaria la actuación.
8 a 10	3	Alto	Es necesaria la actuación cuanto antes.
11 a 15	4	Muy alto	Es necesaria la actuación de inmediato.

Note: Performance levels according to the final score obtained Source:

<https://www.ergonautas.upv.es/metodos/reba/reba-ayuda.php>

With the integration of the partial scores obtained during the evaluation of the different body segments, a final score of 10 points was determined using the REBA method. According to the classification established by this method, this value corresponds to a high level of ergonomic risk, which indicates the need for intervention.

6. CONCLUSIONS.

The ergonomic evaluation carried out at the workstation in the clothing area made it possible to identify the presence of ergonomic risk associated with the postures adopted by the worker during the development of his activities. The application of the REBA method facilitated the systematic analysis of whole-body postures, evidencing postural conditions that represent a risk to musculoskeletal health.

The use of the REBA method proved to be an effective tool for ergonomic assessment in the garment area, allowing to clearly identify the level of postural risk present and providing a reliable ergonomic diagnosis that can serve as a basis for future preventive actions.

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POSTURAL LOAD ANALYSIS TO IMPROVE PERFORMANCE IN FOOD SECTOR WORKERS

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Resumen: Este estudio evalúa los riesgos ergonómicos por carga postural y movimientos repetitivos en el puesto de taquero de trompo en un restaurante local. El objetivo principal fue identificar peligros biomecánicos para desarrollar propuestas de mejora de bajo costo orientadas a reducir los Trastornos Musculoesqueléticos (TME). La metodología incluyó observación directa, registros filmicos y la aplicación del método RULA (Rapid Upper Limb Assessment).

Los resultados arrojaron una puntuación RULA de 6, lo que indica un nivel de riesgo alto que exige intervenciones a corto plazo. Se detectó que el trabajador mantiene el brazo elevado continuamente para alcanzar el punto de corte (puntuación 4) y realiza movimientos repetitivos de muñeca con desviación cubital (puntuación 3), además de una rotación constante del tronco. Estos factores, agravados por temperaturas de entre 38 y 40°C, predisponen al trabajador a patologías como el trauma del manguito rotador, el Síndrome del Túnel Carpiano y la distensión lumbar.

Para mitigar estos riesgos, se propusieron soluciones basadas en la antropometría, incluyendo una plataforma de altura ajustable, reubicación de herramientas en zonas de alcance primario y tapetes antifatiga. El análisis de factibilidad económica determinó que, frente a un costo estimado por lesión de \$36,400 MXN, una inversión de \$20,000 MXN resulta en un Valor Presente Neto (VPN) positivo de \$14,500 MXN. Se concluye que el rediseño ergonómico no solo protege la salud del trabajador, sino que es financieramente viable para el negocio.

Palabras clave: Cocina, RULA, VPN, Trastornos Musculoesqueléticos (TME)

Relevancia para la ergonomía: La importancia de este artículo para la ergonomía radica en que aborda un sector laboral con una alta prevalencia de Trastornos Musculoesqueléticos (TME), este estudio permite cuantificar riesgos críticos que derivan en patologías. Su publicación es fundamental porque integra un análisis de factibilidad económica demostrando científicamente que la inversión ergonómica no solo protege la salud de trabajador, sino que es financieramente rentable.

Abstract: This study evaluates ergonomic risks related to postural load and repetitive movements in the "taquero de trompo" position at a local restaurant. The primary objective was to identify biomechanical hazards to develop low-cost improvement proposals aimed at reducing the incidence of Musculoskeletal Disorders (MSDs). The methodology involved direct observation, video recording, and the application of the RULA (Rapid Upper Limb Assessment) method.

Results yielded a RULA score of 6, indicating a high risk level that requires short-term interventions. It was found that the worker maintains a continuously elevated arm to reach the cutting point (score 4) and performs repetitive wrist movements with ulnar deviation (score 3), alongside constant trunk rotation. These factors, exacerbated by extreme temperatures between 38 and 40°C, predispose the worker to pathologies such as rotator cuff trauma, Carpal Tunnel Syndrome, and lumbar strain.

To mitigate these risks, anthropometry-based solutions were proposed, including an adjustable height platform, relocation of tools to primary reach zones, and anti-fatigue mats. The economic feasibility analysis determined that, compared to an estimated injury cost of \$36,400 MXN, a \$20,000 MXN investment results in a positive Net Present Value (NPV) of \$14,500 MXN. The study concludes that ergonomic redesign not only protects worker health but is also financially viable and enhances operational productivity

Keywords: Kitchen, RULA, VPN, Work-Related Musculoskeletal Disorders

Relevance to Ergonomics: The importance of this article for ergonomics lies in its focus on a labor sector with a high prevalence of Work-Related Musculoskeletal Disorders; this study allows for the quantification of critical risks that lead to pathologies. Its publication is fundamental because it integrates an economic feasibility analysis, scientifically demonstrating that ergonomic investment not only protects the worker's health but is also financially profitable

1. INTRODUCTION

One of the fundamental human needs is nutrition. To meet this need, individuals spend a significant amount of time in the kitchen preparing food that satisfies the caloric requirements of the body. Unfortunately, kitchen tasks are often highly repetitive, which leads to the long-term development of physical ailments among kitchen workers. Márquez and Márquez (2015) state that university cafeterias show high morbidity rates, which in turn generate absenteeism. Furthermore, they report that the diagnosis of Musculoskeletal Disorders (MSDs) reaches 100% among kitchen assistants, with 35% having suffered from this pathology. Additionally, the handling of heavy pots and the inadequate height of burners contribute to lower back pain (Parada and Santos, 2020). Similarly, Valbuena (2023) notes that cutting food with knives or scissors are highly routine activities in the kitchen, occupying nearly 50% of the workday and resulting in a high probability of injury.

One such repetitive activity is found in the role of the *taquero de trompo*, a position frequently seen in restaurant kitchens where traditional tacos are sold. The conditions under which a *taquero* performs are crucial for ensuring both productivity and safety. Therefore, it is a priority to first evaluate the activities performed, especially since labor laws mandate the assessment of working conditions for every job position to determine if the activity can cause Cumulative Trauma Disorders (CTD). Regarding this, Ocaña, Chaca Montenegro, and Medina (2025) mention that current regulations concerning workplace evaluations are limited and empirical. In relation to kitchen environments, they point out a lack of specific ergonomic criteria.

The objective of the present research is to evaluate ergonomic risks caused by postural load and repetitive movements in the *taquero de trompo* position, in order to develop low-cost improvement proposals aimed at reducing Musculoskeletal Disorders

2. METODOLOGY

2.1 Activity Selection



Figure 2.1 Trompo Taquero

A direct site visit was conducted at a local restaurant, where the kitchen area and the role of the vertical-spit taco chef (*taquero de trompo*) were selected due to the high biomechanical demands observed. For subsequent analysis, film (video) and photographic records were taken to identify the critical cutting and preparation tasks of the chef (see Figure 1.1). Through these means, the worker was closely observed while cutting meat and preparing tacos to identify human-task interactions.

2.2 Risk Identification

To support the selection of the activity, an ergonomic checklist was applied. This tool allowed for the collection of objective evidence regarding deficiencies in the workstation dimensions and symptoms reported by the worker prior to applying any formal evaluation method. Potential risks were identified and classified into four main categories: postural risks, movement risks, environmental risks, and safety risks.

2.3 Application of the Ergonomic Tool (RULA)

An ergonomic evaluation was conducted using the RULA (Rapid Upper Limb Assessment) method via a field datasheet. This method allowed for the quantification

of postural load based on the previously captured video, resulting in a score of 6. This indicates a high risk level that requires changes in the short term.

2.4 Analysis of Musculoskeletal Disorders (MSDs)

The assessment was not limited to posture, movement frequency, or applied force; rather, these findings were linked to the probability of developing specific disorders. Contributing factors and long-term effects were analyzed.

2.5 Development of Proposals and Economic Analysis

Finally, the study concluded with a solution and financial validation phase. Solutions were proposed based on anthropometry, workstation design principles, and Industry 4.0 technologies. An economic evaluation of the improvement proposals was conducted to justify the benefits that an investment can bring to the tasks performed by a taquero. The NPV (Net Present Value) was calculated to justify the implementation of anti-fatigue mats and how these benefit both human health and productivity.

3. RESULTS

3.1 Ergonomic Evaluation Results

Método R.U.L.A. Hoja de Campo

A. Análisis de brazo y muñeca
Paso 1: Localizar la posición del brazo

Paso 1a: Corregir...

Paso 2: Localizar la posición del antebrazo

Paso 2a: Corregir...

Paso 3: Localizar la posición de la muñeca

Paso 3a: Corregir...

Paso 4: Círculo de muñeca

Paso 5: Localizar puntuación postural en Tabla A

Paso 6: Añadir puntuación utilización muscular

Paso 7: Añadir puntuación de la fuerza/carga

Paso 8: Localizar fila en Tabla C

CALIFICACIÓN

Tabla A

Ángulo	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
1	1	2	3	4	5	6	7	8	9	10	11	12	13
2	1	2	3	4	5	6	7	8	9	10	11	12	13
3	1	2	3	4	5	6	7	8	9	10	11	12	13
4	1	2	3	4	5	6	7	8	9	10	11	12	13
5	1	2	3	4	5	6	7	8	9	10	11	12	13
6	1	2	3	4	5	6	7	8	9	10	11	12	13
7	1	2	3	4	5	6	7	8	9	10	11	12	13
8	1	2	3	4	5	6	7	8	9	10	11	12	13
9	1	2	3	4	5	6	7	8	9	10	11	12	13
10	1	2	3	4	5	6	7	8	9	10	11	12	13
11	1	2	3	4	5	6	7	8	9	10	11	12	13
12	1	2	3	4	5	6	7	8	9	10	11	12	13
13	1	2	3	4	5	6	7	8	9	10	11	12	13

Tabla B

Ángulo	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
1	1	2	3	4	5	6	7	8	9	10	11	12	13
2	1	2	3	4	5	6	7	8	9	10	11	12	13
3	1	2	3	4	5	6	7	8	9	10	11	12	13
4	1	2	3	4	5	6	7	8	9	10	11	12	13
5	1	2	3	4	5	6	7	8	9	10	11	12	13
6	1	2	3	4	5	6	7	8	9	10	11	12	13
7	1	2	3	4	5	6	7	8	9	10	11	12	13
8	1	2	3	4	5	6	7	8	9	10	11	12	13
9	1	2	3	4	5	6	7	8	9	10	11	12	13
10	1	2	3	4	5	6	7	8	9	10	11	12	13
11	1	2	3	4	5	6	7	8	9	10	11	12	13
12	1	2	3	4	5	6	7	8	9	10	11	12	13
13	1	2	3	4	5	6	7	8	9	10	11	12	13

Tabla C

Ángulo	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
1	1	2	3	4	5	6	7	8	9	10	11	12	13
2	1	2	3	4	5	6	7	8	9	10	11	12	13
3	1	2	3	4	5	6	7	8	9	10	11	12	13
4	1	2	3	4	5	6	7	8	9	10	11	12	13
5	1	2	3	4	5	6	7	8	9	10	11	12	13
6	1	2	3	4	5	6	7	8	9	10	11	12	13
7	1	2	3	4	5	6	7	8	9	10	11	12	13
8	1	2	3	4	5	6	7	8	9	10	11	12	13
9	1	2	3	4	5	6	7	8	9	10	11	12	13
10	1	2	3	4	5	6	7	8	9	10	11	12	13
11	1	2	3	4	5	6	7	8	9	10	11	12	13
12	1	2	3	4	5	6	7	8	9	10	11	12	13
13	1	2	3	4	5	6	7	8	9	10	11	12	13

B. Análisis de cuello, tronco y pierna
Paso 9: Localizar la posición del cuello

Paso 9a: Corregir...

Paso 10: Localizar posición tronco

Paso 10a: Corregir...

Paso 11: Párcos

Paso 12: Buscar puntuación postural en Tabla B

Paso 13: Añadir puntuación uso muscular

Paso 14: Añadir puntuación de fuerza/carga

Paso 15: Localizar columna en Tabla C

Puntuación A (Brazo/Muñeca) = 6

Puntuación Final

6

Puntuación B (Cuello/Tronco) = 4

Resultado de convergencia en Tabla C = Puntuación Final de 6

Empresa: **Tacos Popo's** Puesto/Sección: **Taquero / Area de Trompo** Fecha: **22/12/25**
Referencia: **DIA** Tabla: **Tabla A**

Figure 3.1. RULA Ergonomic Evaluation Results

The evaluation of the vertical-spit taco chef (taquero de trompo) workstation, conducted through the analysis of previously recorded video using the RULA ergonomic tool, resulted in a final score of 6. This classifies the activity within a high-

risk level. According to the method's criteria, this result indicates that modifications to the workstation are necessary to prevent Musculoskeletal Disorders (MSDs). Among the body parts assessed, the following results are of particular note:

- The upper arm obtained a score of 4. This high result is due to the chef maintaining the arm in a continuous elevated and extended position to reach the cutting point of the spit. This posture generates considerable static tension in the deltoid and the rotator cuff.
- The wrist and forearm both received scores of 3. The wrist performs repetitive movements in unnatural positions involving ulnar deviation and extension to maintain the cutting angle, which increases the risk of tendonitis and carpal tunnel syndrome.
- The trunk received a score of 3 due to slight flexion and rotation to the right to find the optimal cutting angle. This sustained posture overloads the intervertebral discs and lumbar muscles.

The fixed height of the spit forces the shoulder to remain raised; the combination of extreme frequency and sustained static effort causes muscle ischemia, accelerating the onset of fatigue and pain. Although RULA primarily evaluates posture, extreme temperatures between 38°C and 40°C were detected. These conditions reduce muscle endurance and worsen the worker's posture, further aggravating the results obtained.

3.2 Analysis of Musculoskeletal Disorders (MSDs)

Derived from the RULA ergonomic evaluation, it was identified that the current workstation design and the repetitive nature of the task predispose the chef to various musculoskeletal disorders. The limbs with the highest risk scores and their potentially associated pathologies are:

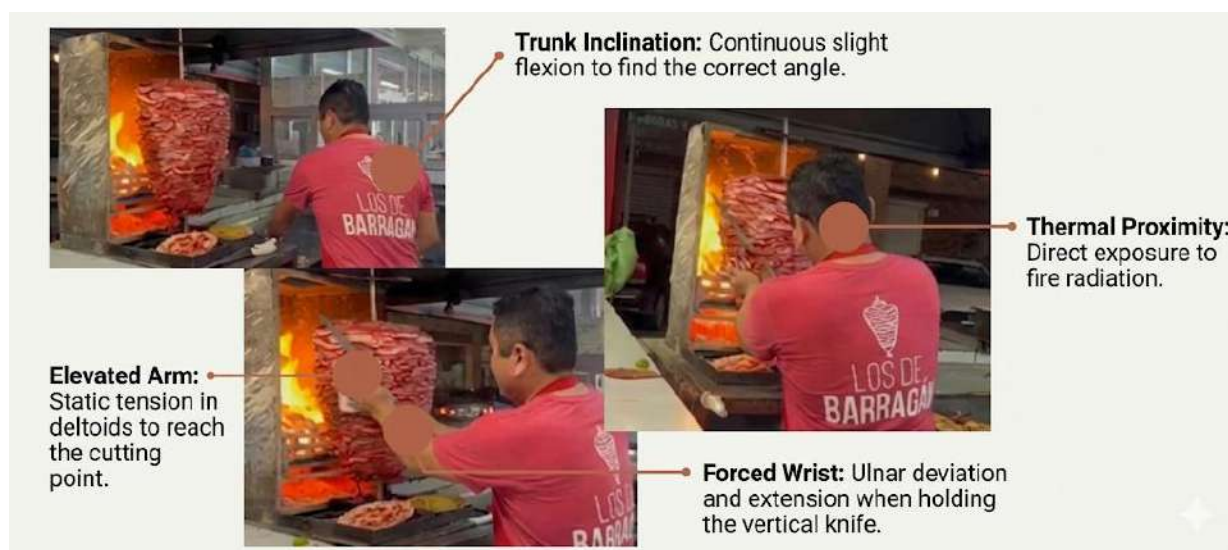


Figure 3.2. Musculoskeletal Injuries

3.2.1 Shoulder and Arm

The analysis of shoulder disorders reveals that the vertical-spit taco chef faces a high risk of developing Rotator Cuff Syndrome, due to the constant elevation of the arm above the neutral posture and sustained static loading during extended work shifts. These disorders are driven by critical factors such as the repetitive forward cutting motion, static load on the shoulder, and compensatory movements resulting from heat-exposure fatigue, all of which subject the rotator cuff tendons and the deltoid muscle to severe tension. As a long-term consequence, the worker may suffer from chronic pain, stiffness, weakness, and a significant reduction in range of motion (ROM)—conditions that, if not corrected through workstation intervention, could progress toward partial tears that compromise functional capacity.

3.2.2 Wrist and Hand

The evaluation of the wrist and hand reveals a critical risk due to the extreme frequency and repetitiveness of the cutting movements, which are performed in very short cycles that do not allow for tendon and muscle recovery. Factors such as a forceful grip on the knife, along with wrist deviation and extension, significantly increase the probability of developing Carpal Tunnel Syndrome (CTS) due to median nerve compression. Associated symptoms, including pain, numbness, and tingling, can progress over the long term toward chronic muscle weakness and decreased grip strength.

3.2.3 Back and Trunk

Although trunk flexion is not extreme, the constant rotation required to follow the shape of the spit generates cumulative strain that can lead to disorders such as lumbar muscle strain and the risk of disc degeneration or herniation due to repeated rotational stress. Prolonged static posture combined with trunk twisting are the primary contributing factors.

3.3 Anthropometry-Based Solutions

The following proposals seek to adapt the physical environment to the dimensions of the human body to reduce fatigue and muscular stress:



Figure 3.3. Vertical-Spit Taco Chef (Taquero de Trompo) Improvements

1. An adjustable-height platform is proposed under the spit to position the cutting point at the worker's elbow height, reducing the static load on the shoulder and rotator cuff.
2. Relocate frequent tools and ingredients—such as tortillas, knives, and salsas—within the primary reach zone (30 to 40 centimeters) to minimize unnecessary trunk twisting.
3. Implement a contoured/angled-handle knife that allows the wrist to maintain a neutral posture, reducing the risk of Carpal Tunnel Syndrome.
4. Install anti-fatigue mats to reduce the load on the legs and lower back, improving circulation during 8-to-12-hour shifts.

3.4 Solutions Based on Industrial Design Principles

1. Workstation redesign into a "U" shape, allowing access to all elements with minimal movement.
2. Install transparent, heat-resistant shields between the spit and the chef to reduce direct exposure to thermal radiation and the risk of burns.
3. Improve visibility using directed LED lighting in cutting zones to reduce eye strain and prevent accidents with sharp objects.
4. Use heat-resistant gloves for the non-dominant hand and cut-resistant gloves, along with protective sleeves against grease splashes.

3.5 Application of Industry 4.0 and Technology

Although the investment may be higher, these technologies increase safety and efficiency during the chef's operation.

1. Temperature sensors to monitor the spit in real-time to avoid overheating and ensure taco quality.
2. Digital order displays (KDS) to replace paper notes with monitors, reducing cognitive load and multitasking stress.
3. An automated extraction system that adjusts based on detected heat and smoke levels.

3.6 Economic Feasibility and Cost-Benefit Analysis

To mitigate the risk level of 6 shown in the RULA ergonomic evaluation, an intervention level is proposed across three possible categories:

Table 3.1 Investment Costs

Category	Investment Level	Recommended Priority
Low Investment	\$3,000 - \$7,000 MXN	Mats, Knives, PPE.
Medium Investment	\$8,000 - \$20,000 MXN	Platform, Thermal barriers, Lighting.
High Investment	\$25,000+ MXN	Structural redesign, Ventilation, KDS Displays.

The cost of omitting these improvements translates directly into the development of Musculoskeletal Disorders (MSDs). A single case of rotator cuff injury or carpal tunnel syndrome represents medical expenses, including diagnostic studies and physical rehabilitation, estimated at \$12,500 MXN.

Regarding indirect costs, such as absenteeism—where the chef is unable to work due to an MSD—this would reflect an average loss of 21 disability days. Consequently, a replacement chef would need to be hired, leading to a loss of efficiency due to the learning curve, estimated at \$23,900 MXN. This results in a total estimated cost per injury of \$36,400 MXN.

With a medium-level investment of \$20,000 MXN and a potential expense reduction per incident of \$36,400, using an annual discount rate of 10%, the NPV (Net Present Value) calculation is positive at \$14,500. This indicates that the investment project is economically viable as it brings financial benefits to the business. Furthermore, it avoids intangible costs such as the deterioration of the organizational climate and the risk of lawsuits or fines for non-compliance with occupational health regulations (NOM-036-STPS).

4. CONCLUSION

Bracho (2011) notes that in industrial cafeterias, cooking positions present the most critical and uncomfortable postures, posing a high risk of developing MSDs. This aligns with the present research, where the vertical-spit taco chef maintains their arms in a continuously raised and extended position to reach the cutting point. Likewise, Bracho (2011) concludes that the height of kitchen tools and instruments is often excessive—situated well above eye level and vertical reach. This is consistent with the taquero's workstation, where they must raise their shoulders toward the spit to prepare the taco, resulting in a high RULA score.

In their research, Godoy and Castellanos (2018) mention applying the REBA evaluation to kitchen tasks and detecting the use of cutting tools above shoulder height. This coincides with the current study, which applied a closely related method (RULA), identifying that the taquero position is prone to developing rotator cuff syndrome due to constant shoulder elevation.

Finally, Ballesteros and Rico (2021) emphasize the importance of making changes in "cold kitchens" due to the high volume of repetitive movements and efforts. This supports the present research, where the taquero's activity is highly repetitive, leading to the proposal of an investment to improve working conditions.

Molina et al. (2018) state that kitchen workers are often unaware of correct postures and the laws that protect them, which can lead to physical overexertion and musculoskeletal discomfort. While this study did not focus on training, it is undoubtedly a necessary step that could help reduce the prevalence of MSDs among taqueros.

The present research fulfills the general objective of evaluating ergonomic risks in the vertical-spit taco chef position and developing economically justified improvement proposals. The position was successfully evaluated using the RULA

method, postural findings were linked to the probability of developing MSDs, and tangible, accessible solutions based on anthropometry were proposed.

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ERGONOMIC ASSESSMENT AND RISK ASSESSMENT AT AUTOMOTIVE EXTERIOR SHAPING AND COATING STATIONS

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Resumen: El sector de mantenimiento automotriz en México representa un pilar económico estratégico; no obstante, a nivel estatal en Sinaloa y local en Guasave, las micro y pequeñas empresas de este rubro enfrentan desafíos críticos en salud ocupacional. Estadísticamente, los operarios de carrocería y pintura presentan una alta prevalencia de lesiones musculoesqueléticas (LME), principalmente en la región lumbar (40%) y extremidades superiores (35%), derivadas de posturas forzadas y movimientos repetitivos.

El objetivo de esta investigación es evaluar las condiciones ergonómicas en un taller de carrocería y pintura para reducir riesgos laborales y optimizar la productividad. La metodología empleada es de corte descriptivo y transversal, centrada en la aplicación del método RULA (Rapid Upper Limb Assessment) en dos estaciones críticas de trabajo. Asimismo, se integran principios de diseño ergonómico y se verifica el cumplimiento de las normativas de la Secretaría del Trabajo y Previsión Social (STPS), específicamente la NOM-036-1-STPS-2018 sobre factores de riesgo ergonómico y la NOM-017-STPS-2008 relativa al equipo de protección personal. Los resultados preliminares indican niveles de actuación críticos (puntuaciones RULA de 6 y 7), lo que exige cambios inmediatos en el diseño de las estaciones. Se concluye que la reingeniería de procesos, basada en la antropometría y capacitación continua, permitirá mitigar la fatiga laboral y el ausentismo, sino también elevar los estándares de calidad y eficiencia operativa en el sector local.

Palabras claves: Método RULA, Diseño ergonómico, Sector automotriz

Relevancia para la ergonomía: La ergonomía es la interacción entre los seres humanos y otros elementos de un sistema. Este estudio aporta información que contribuye a la mejora de las condiciones de trabajo del sector Automotrices.

Abstract: The automotive maintenance sector in Mexico represents a strategic economic pillar; however, at the state level in Sinaloa and the local level in Guasave,

micro and small businesses in this sector face critical challenges in occupational health. Statistically, auto body and paint shop workers exhibit a high prevalence of musculoskeletal disorders (MSDs), primarily in the lumbar region (40%) and upper extremities (35%), resulting from forced postures and repetitive movements.

The objective of this study is to evaluate ergonomic conditions in an auto body and paint shop to reduce occupational risks and optimize productivity. The methodology employed is descriptive and cross-sectional, focused on the application of the RULA (Rapid Upper Limb Assessment) method at two critical workstations. Additionally, ergonomic design principles are integrated, and compliance with the regulations of the Ministry of Labor and Social Welfare (STPS) is verified. Preliminary results indicate critical action levels (RULA scores of 6 and 7), which require immediate changes to the design of the workstations. It is concluded that process reengineering, based on anthropometry and ongoing training, will not only mitigate work-related fatigue and absenteeism but also raise standards of quality and operational efficiency in the local sector.

Keywords: RULA method, Ergonomic design, Automotive industry.

Relevance to ergonomics: Ergonomics is the interaction between humans and other elements of a system. This study provides information that contributes to improving working conditions in the automotive industry.

1. INTRODUCTION

In the automotive maintenance and repair sector, operational activities require a high degree of physical exertion, characterized by awkward postures and prolonged repetitive movements. These conditions pose critical ergonomic risks that, if not addressed in a timely manner, can lead to musculoskeletal disorders (MSDs). Global research in the field of occupational health within the automotive sector indicates that between 60% and 80% of workers experience painful symptoms at some point in their working lives, requiring prolonged rehabilitation processes in severe cases (Mondelo et al., 2020).

Nationally, according to statistics from the Mexican Social Security Institute (IMSS, 2024), MSDs constitute one of the leading causes of occupational illness. It is estimated that 24.7% of recorded occupational illnesses are directly linked to ergonomic risk factors, primarily affecting the spine, joints, and soft tissues due to physical overload. Given this situation, prevention through the early identification of risk factors stands as the most effective strategy for mitigating the incidence of these conditions.

This study focuses on “Taller de Carrocería Pilar,” a company specializing in automotive repair and detailing in Guasave, Sinaloa. The organization has a staff of 15 employees, 9 of whom work directly in the areas of disassembly, body repair, and painting, with an 8-hour workday on weekdays and a 6-hour workday on Saturdays. Currently, the company faces critical productivity challenges, manifested in missed delivery deadlines and consequent customer dissatisfaction. It has been determined

that these delays stem from poor operational coordination and limited workspace, factors that lead to unnecessary movement, ergonomically unsound postures, and unproductive downtime. Therefore, this research aims to diagnose these issues and propose improvements using an approach grounded in industrial engineering and participatory ergonomics.

2. OBJECTIVE

Assess ergonomic conditions and determine the levels of musculoskeletal risk at the bodywork and painting stations in the “Pilar” Body Shop and Paint Shop by applying the RULA method and analyzing STPS regulations, with the aim of designing intervention strategies that optimize worker well-being and operational productivity

3. METHODOLOGY

1. Conduct an assessment of the company's production process through on-site inspections, identifying worker characteristics and job tasks that pose risks to operator health and safety. This is achieved by applying STPS standards and ergonomic principles to evaluate ergonomic conditions.

2. Determine the ergonomic risk factors at the parts disassembly, body repair, and painting stations in the Body Shop, such as awkward postures and the application of excessive force. To this end, assessments are conducted to identify musculoskeletal injuries and cumulative trauma disorders using ergonomic evaluation methods such as the RULA method.

3. Design ergonomic and safety conditions in the quality control laboratory to ensure improved productivity.

4. RESULTS

A comprehensive assessment of the “Pilar” Body Shop and Paint Shop identified various ergonomic risk factors that compromise both the physical well-being of the workers and the efficiency of the production system. The technical analysis confirmed the systematic presence of physical overexertion, highly repetitive work cycles, and prolonged exposure to environmental conditions. A postural assessment and symptom screening were conducted using the RULA (Rapid Upper Limb Assessment) method, which identified critical action levels (final scores of 6 and 7), requiring immediate intervention. The areas requiring the most attention are trunk flexion, the adoption of asymmetrical postures, and the handling of excessive static loads. These findings were corroborated through observation during the site visits and the application of ergonomic principles, which allowed for the mapping of the most problematic areas.

Furthermore, the use of standard perception survey tools identifies the risks to which workers are exposed due to high postural strain and fatigue resulting from

their daily activities, thereby validating the consistency of the results obtained through biomechanical methods.

Regulatory Compliance Assessment

A technical audit was conducted based on the current legal framework of the Ministry of Labor and Social Welfare (STPS). The compliance analysis yielded the following observations: Physical Agents: Conditions related to noise (NOM-011-STPS-2001), high thermal conditions (NOM-015-STPS-2001), vibrations (NOM-024-STPS-2001), and lighting (NOM-025-STPS-2008) were evaluated.

Psychosocial Factors: NOM-035-STPS-2018 was applied to identify severe traumatic events and favorable organizational environments.

The comprehensive assessment reveals that current working conditions do not meet minimum occupational safety and health standards. The identified risks, both biomechanical and environmental, confirm the imperative need to implement an ergonomic redesign of the workstations. This intervention must focus on adapting the environment to the worker's capabilities to mitigate the onset of occupational diseases and optimize the workshop's overall productivity.

The production process and the company's work areas were identified



Figure 1 Assembly Workstation 1



Figure 2. and painting workstation



Figure 3. Company process diagram

The company's production process consists of 12 operations, which include the two workstations.

Table 1. Identification of Official Mexican Standards of the STPS applied to workstation 1 y 2

List of official Mexican Standards applied to the production process of the company			
Company: Taller PILAR			
Line of business: Workstation 1 y 2			
Date: March 22,2026			
Standard	Yes	No	Observations
Official Mexican Standard NOM-036-1-STPS-2018, Ergonomic risk factors at work – Manual handling of loads.		X	Workers perform manual handling of materials and tools in inadequate positions, such as bending and lifting from ground level, without proper ergonomic conditions.
Official Mexican Standard NOM-035-STPS-2018, Psychosocial risk factors at work – Identification, analysis and prevention		X	Long working hours and physical workload may contribute to fatigue and stress, without evidence of evaluation or preventive measures.
Official Mexican Standard NOM-001-STPS-2008, Buildings, premises, facilities and areas in workplaces – Safety conditions	X		The work area presents acceptable general conditions; however, improvements are needed in the organization and layout to reduce ergonomic risks.
Official Mexican Standard NOM-024-STPS-2001, Vibrations – Safety and hygiene conditions in the workplace		X	.Equipment used in the area may generate vibrations, and no control measures or preventive maintenance were identified.
Official Mexican Standard NOM-011-STPS-2001, Safety and hygiene conditions in workplaces where noise is generated		X	There is no evidence of noise level measurements or use of hearing protection, exposing workers to potential risk.

Table 2. Ergonomic principles applied to workstation 1 and 2

Principles	Remarks
Principle 2: Use the elbow height as a reference.	It is recommended that activities be performed at elbow height, whether standing or sitting, since the physical effort required may increase when working above or below this level. In the workshop, you can see how some activities are performed with an extended reach but with poor posture.
Principle 4: Find the correct position for each task.	Workers may assume different positions to perform their tasks; however, these postures are not always appropriate
Principle 6: Minimize fatigue Many times workers overtax their physical capacity by doing activities that can cause muscle damage	As you can see, the work isn't always physically demanding, since the workload is distributed. However, these tasks are performed at a slow pace, and fatigue can set in if they aren't done correctly.
Principle 7: Minimize direct pressure.	Stress can arise during certain tasks, which workers may not always recognize; this can affect their comfort and may lead to long-term physical problems
Principle 8: Adjustment and change of posture	As you can see, during these activities you can change your posture, which helps reduce physical strain and allows workers to move around, stretch, and adjust their position, thereby improving ergonomic conditions throughout the workday
Principle 9: Provide space and access It is of great importance that working space is provided for each element and easy access to whatever is needed.	The work areas are generally spacious, but materials tend to pile up, which reduces efficiency and obstructs movement
Principle 12: Improve the organization of the work If the tool trolley were well organized,	The work environment is good in terms of teamwork and communication, and employees have access to recreational areas; however, the layout needs to be improved, and better organization of the space is needed. This will help reduce the time wasted looking for tools.

Based on the ergonomic analysis conducted, low compliance with STPS regulations was identified. NOM-025-STPS-2008 is not being met due to insufficient lighting in some work areas. Regarding NOM-011-STPS-2001, it was observed that workers are exposed to very high noise levels that exceed the permitted limits. With respect to NOM-001-STPS-2008, there is insufficient documentary evidence regarding vibration monitoring, nor are medical evaluations conducted on workers. Finally, regarding NOM-015-STPS-2001, high humidity was detected in some areas, which affects thermal comfort and causes physical discomfort; this standard establishes appropriate conditions for exposure to temperatures. In the workshop, temperatures range between 42 and 48 degrees, creating an inadequate thermal environment that causes fatigue and mental exhaustion.

4.1. Application of ergonomic evaluation methods in workstations 1 y 2

Método R.U.L.A. Hoja de Campo

A. Análisis de brazo, antebrazo y muñeca

Paso 1: Localizar la posición del brazo

Si el hombro está elevado: +1
Si el brazo está abducido (despegado del cuerpo): +1
Si el brazo está apoyado o sostenido: -1

Puntuación brazo = 1

Paso 2: Localizar la posición del antebrazo

Paso 2a: Corregir...
Si el brazo cruza la línea media del cuerpo: -1
Si el brazo sale de la línea del cuerpo: +1

Puntuación antebrazo = 2

Paso 3: Localizar la posición de la muñeca

Paso 3a: Corregir...
Si la muñeca está doblada por la línea media: -1

Puntuación muñeca = 2

Paso 4: Giro de muñeca

Si la muñeca está en el rango medio de giro: +1
Si la muñeca está girada próxima al rango final de giro: +2

Puntuación giro de muñeca = 1

Paso 5: Localizar puntuación postural en Tabla A

Utilizar valores de pesos 1, 2, 3 y 4 para localizar puntuación postural en Tabla A

Puntuación postural A = 2

Paso 6: Añadir puntuación utilización muscular

Si la postura es principalmente estática (p.e. agarres superiores a 1 min.) ó si sucede repetidamente la acción (4 veces/min. ó más): +1

Puntuación muscular = 1

Paso 7: Añadir puntuación de la Fuerza / Carga

Si carga ó esfuerzo < 2 Kg. intermitente: +0
Si es de 2 a 10 Kg. estática o repetitiva: +2
Si es una carga > 10 Kg. ó vibrante ó súbita: +3

Puntuación fuerza/carga = 0

Paso 8: Localizar fila en Tabla C

Ingresar a Tabla C con la suma de los pasos 5, 6 y 7

Puntuación final muñeca, antebrazo y brazo = 3

B. Análisis de cuello, tronco y pierna

Paso 9: Localizar la posición del cuello

Si hay rotación: +1; Si hay inclinación lateral: +1
Si hay extensión, cualquier ángulo

Puntuación cuello = 2

Paso 10: Localizar la posición del tronco

Paso 10a: Corregir...
Si hay torsión: +1; Si hay inclinación lateral: +1

Puntuación tronco = 5

Paso 11: Localizar la posición de la pierna

Si piernas y pies apoyados y equilibrados: +1
Si no: -2

Puntuación piernas = 1

Paso 12: Localizar puntuación postural en Tabla B

Utilizar valores de pesos 5, 10 y 11 para localizar puntuación postural en Tabla B

Puntuación postural B = 6

Paso 13: Añadir puntuación utilización muscular

Si la postura es principalmente estática (p.e. agarres superiores a 1 min.) ó si sucede repetidamente la acción (4 veces/min. ó más): +1

Puntuación uso muscular = 1

Paso 14: Añadir puntuación de la Fuerza / Carga

Si carga ó esfuerzo < 2 Kg. intermitente: +0
Si es de 2 a 10 Kg. estática o repetitiva: +2
Si es una carga > 10 Kg. ó vibrante ó súbita: +3

Puntuación fuerza/carga = 0

Paso 15: Localizar columna en Tabla C

Ingresar a Tabla C con la suma de los pasos 12, 13 y 14

Puntuación final cuello, antebrazo y brazo = 7

Empresa: _____ **Fecha:** _____

Puesto / Sección: _____

Referencias: _____

Observador: _____ **Firma:** _____

Puntuación Final: 1 ó 2: Aceptable; 3 ó 4: Ampliar el estudio; 5 ó 6: Ampliar el estudio y modificar pronto; 7: estudiar y modificar inmediatamente

Figure 4. Application of the RULA Method in workstation 1

Método R.U.L.A. Hoja de Campo

A. Análisis de brazo, antebrazo y muñeca
Paso 1: Localizar la posición del brazo

Puntuación brazo = 1

Paso 2: Localizar la posición del antebrazo

Puntuación antebrazo = 2

Paso 3: Localizar la posición de la muñeca

Puntuación muñeca = 2

Paso 4: Giro de muñeca

Puntuación giro de muñeca = 1

Paso 5: Localizar puntuación postural en Tabla A

Puntuación postural A = 2

Paso 6: Añadir puntuación utilización muscular

Puntuación muscular = 1

Paso 7: Añadir puntuación de la fuerza / Carga

Puntuación fuerza/carga = 0

Paso 8: Localizar fila en Tabla C

Puntuación final muñeca, antebrazo y brazo = 3

B. Análisis de cuello, tronco y pierna
Paso 9: Localizar la posición del cuello

Puntuación cuello = 2

Paso 10: Localizar la posición del tronco

Puntuación tronco = 5

Paso 11: Localizar la posición de la pierna

Puntuación pierna = 1

Paso 12: Localizar puntuación postural en Tabla B

Puntuación postural B = 7

Paso 13: Añadir puntuación utilización muscular

Puntuación uso muscular = 1

Paso 14: Añadir puntuación de la fuerza / Carga

Puntuación fuerza/carga = 0

Paso 15: Localizar columna en Tabla C

Puntuación final cuello, tronco y pierna = 7

Tabla A

Brazo	Antebrazo	Mano	1	2	3	4
1	1	1	1	2	2	3
2	2	2	2	3	3	4
3	3	3	3	4	4	5
4	4	4	4	5	5	6
5	5	5	5	6	6	7
6	6	6	6	7	7	8
7	7	7	7	8	8	9
8	8	8	8	9	9	10
9	9	9	9	10	10	11
10	10	10	10	11	11	12

Tabla B

Cuello	Tronco	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2	2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
3	3	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
4	4	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
5	5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
6	6	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
7	7	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
8	8	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
9	9	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
10	10	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
11	11	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	
12	12	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
13	13	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
14	14	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
15	15	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	
16	16	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	
17	17	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
18	18	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
19	19	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
20	20	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
21	21	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	
22	22	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
23	23	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	
24	24	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	
25	25	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	
26	26	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	
27	27	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	
28	28	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	
29	29	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	
30	30	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	
31	31	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	
32	32	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	
33	33	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	
34	34	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	
35	35	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	
36	36	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
37	37	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	
38	38	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	
39	39	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	
40	40	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	
41	41	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	
42	42	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	
43	43	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	
44	44	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	
45	45	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	
46	46	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	
47	47	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	
48	48	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	
49	49	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	
50	50	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	
51	51	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	
52	52	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	
53	53	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	
54	54	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	
55	55	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	
56	56	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	
57	57	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	
58	58	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	
59	59	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	

at heights beyond their reach, forcing them into awkward postures that cause excessive bending of the torso, knees, back, and neck; they are also affected by exposure to various chemicals.

The application of ergonomic assessment methods, such as the RULA method, at the two workstations helped identify cumulative trauma disorders (CTDs) where human errors and repetitive movements, physical overexertion, and prolonged exposure are present at both workstations. The results indicate risk levels that require immediate changes to operations and work tools to prevent musculoskeletal injuries, accumulated fatigue, and decreased work performance.

Based on the results obtained, improvement proposals were put forward focused on the ergonomic redesign of workstations, the acquisition of lifts, ramps, and supports for parts or adjustable tables, as well as the implementation of ergonomic workbenches. This would help prevent the need to bend the body and neck and avoid incorrect postures while working, ensuring that operators do not work in an uncomfortable manner and can work more quickly. In the painting area, it is recommended to use personal protective equipment to avoid exposure to harmful fumes, as stipulated by NOM-017-STPS-2008.

The benefits of these improvements would include reduced fatigue and injuries, improved posture, and enhanced organization among workers, enabling them to perform tasks more quickly and efficiently. Finally, establishing a monitoring and control program is essential to ensure the effectiveness of the proposed improvements, allowing for continuous evaluation of working conditions.

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INTEGRATED ERGONOMIC ASSESSMENT AND REDESIGN PROPOSAL FOR AN ADMINISTRATIVE COMPUTER WORKSTATION: A WORK EVALUATION CASE STUDY IN A MEXICAN HIGHER-EDUCATION INSTITUTION

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Resumen: El presente estudio analiza una estación de trabajo administrativa en una institución de educación superior, ocupada por una usuaria de 42 años. Bajo un enfoque de sistemas, se evaluaron factores dimensionales, posturales y ambientales utilizando herramientas especializadas. Se empleó el método ROSA como indicador principal para el entorno de oficina, complementado con RULA para la carga biomecánica y el método LEST para auditar variables del entorno físico como iluminación, ruido y temperatura.

Los resultados convergen en un nivel de riesgo muy alto, lo que exige una intervención correctiva inmediata. Entre los hallazgos críticos destaca un déficit de iluminación de 85 lx, cifra que representa una carencia del 70% respecto al estándar de 300 lx para tareas administrativas. Esta condición, sumada al uso predominante de una computadora portátil sin periféricos, propicia fatiga visual, una flexión cervical sostenida y falta de apoyo en las extremidades.

Para mitigar estos riesgos, se proponen controles de bajo costo y alta factibilidad. Estas medidas incluyen la implementación de un asiento ergonómico adaptativo diseñado para optimizar el soporte lumbar y la postura pélvica. Asimismo, se recomienda elevar la pantalla al nivel de la vista e integrar un teclado externo y un ratón vertical. Con estas adecuaciones, se proyecta reducir el nivel de riesgo de una categoría "muy alta" a un rango de "bajo a moderado".

Palabras clave: Análisis ergonómico, Riesgo musculoesquelético, Diseño de un prototipo, ROSA, LEST.

Relevancia para la ergonomía: Este trabajo aporta una plantilla de evaluación laboral replicable y fundamentada en estándares para entornos administrativos con

equipos de visualización de datos (PVD), la cual combina verificaciones de cumplimiento ambiental con una evaluación postural multimétodo y una proyección de reducción de riesgos. En términos prácticos, destaca cómo el riesgo en oficinas puede subestimarse si solo se utilizan índices centrados en la fuerza, y demuestra cómo el método ROSA puede servir como un indicador orientado a la toma de decisiones en el rediseño de oficinas. Este enfoque apoya la práctica de la ergonomía ocupacional en instituciones educativas al vincular déficits ambientales medibles (por ejemplo, la iluminancia) con la postura observada y con controles de ingeniería o administrativos accionables.

Abstract: This study analyzes an administrative workstation in a higher-education institution, occupied by a 42-year-old female worker. Under a systems approach, dimensional, postural, and environmental factors were evaluated using specialized tools. The ROSA method was employed as the primary indicator for the office environment, complemented by RULA to assess biomechanical load and the LEST method to audit physical environment variables such as lighting, noise, and temperature.

The results converge on a very high-risk level, requiring immediate corrective intervention. Among the critical findings, a lighting deficit of 85 lx stands out, representing a 70% shortfall compared to the 300 lx criterion for administrative tasks. This condition, combined with the predominant use of a laptop without external peripherals, promotes visual fatigue, sustained cervical flexion, and a lack of limb support.

To mitigate these risks, low-cost and high-feasibility controls are proposed. These measures include the implementation of an adaptive ergonomic seat designed to optimize lumbar support and pelvic posture. Additionally, it is recommended to elevate the screen to eye level and integrate an external keyboard and a vertical mouse. With these adjustments, the risk level is projected to be reduced from a "very high" category to a "low to moderate" range.

Keywords: Ergonomic analysis, Musculoskeletal risk, Prototype Design, ROSA, LEST.

Relevance to ergonomic: This work contributes a replicable, standards-informed work evaluation template for administrative display screen equipment (DSE) settings that combines environmental compliance checks with multimethod postural assessment and a risk reduction projection. Practically, it highlights how office risk may be underestimated if only force-focused indices are used, and it demonstrates how ROSA can serve as a decision-oriented indicator in office redesign. This approach supports occupational ergonomics practice in educational institutions by linking measurable environmental deficits (e.g., illuminance) to observed posture and to actionable engineering and administrative controls.

1. INTRODUCTION

Office work in higher-education institutions increasingly depends on prolonged

display screen equipment (DSE) use, with many administrative tasks performed in static seated postures for extended periods. Prior research consistently shows that prolonged computer use, poor monitor height, non-neutral neck and upper-limb postures, and suboptimal chair/peripheral configuration are associated with musculoskeletal symptoms, discomfort, and reduced work quality in office personnel (de Barros et al., 2022; Supian et al., 2023; Fajria & Ismiyah, 2024). At the same time, office ergonomics should not be analyzed only from a postural perspective: human factors and ergonomics (HFE) guidelines emphasize a systems approach that integrates the worker, task, tools, and environment to protect health while sustaining performance (ILO & IEA, 2021). In this context, lighting becomes a critical co-determinant of risk because deficient illuminance and glare can increase visual and mental fatigue and may promote compensatory head/neck postures during screen work; experimental evidence also indicates that light source position and color temperature influence visual and mental fatigue outcomes (Khajeh et al., 2023). Methodologically, there is still limited evidence based on standardized risk assessments to quantify office risk reduction after interventions, which strengthens the value of office-specific instruments such as ROSA alongside complementary methods such as RULA/OWAS/LEST (de Barros et al., 2022). In parallel, recent workstation-redesign studies in administrative contexts highlight the importance of anthropometric adaptation and prototype-based solutions to improve comfort, productivity, and injury prevention (Benavides-Vazquez & Rodriguez-Llerena, 2024). Therefore, this abstract presents an integrated ergonomic evaluation of a single administrative workstation in a Mexican higher-education institution and a standards-oriented redesign proposal, with emphasis on a practical prototype and low-cost controls feasible in resource-constrained institutional environments.

2. OBJECTIVES

2.1 General:

To perform an integrated ergonomic evaluation of an administrative workstation covering dimensional, postural, and environmental factors and to propose a redesign that improves worker health and performance while meeting applicable requirements.

2.2 Specific:

- a) To assess the disposition and accessibility of displays and input devices.
- b) To measure key physical-environment variables (illumination, thermal conditions, and noise) and contrast them against reference criteria.
- c) To apply complementary observational assessment methods to identify biomechanical and office-specific risks.
- d) To estimate the expected risk reduction after implementing targeted improvements.

3. SCOPE AND DELIMITATION

The evaluation was delimited to one individual administrative workstation located in the Industrial Engineering administrative office at the TecNM campus Cd. Cuauhtémoc. The user was a 42-year-old female worker with a one-year tenure, but more than ten years in the institution, performing office and computer tasks during an eight-hour shift (approximately six hours seated at the workstation). The study focused on physical, geometric, and environmental ergonomics and did not include physiological measurements, productivity time at motion analyses, or psychosocial risk assessment.

4. METHODOLOGY

A cross-sectional workstation assessment was conducted using:

- a) A structured checklist for general workstation conditions.
- b) Dimensional measurements of furniture and reach distances.
- c) Environmental measurements. Illumination (lux) was measured on the work plane using a digital lux meter; ambient temperature (°C) was recorded using a digital thermometer; and sound pressure levels (dB) were obtained using a calibrated mobile sound level application.

Postural and task risk were assessed using multiple methods to capture complementary aspects of work: BRIEF for baseline ergonomic risk identification, RULA for upper limb and neck/trunk posture, LEST for work conditions including the physical environment, OWAS for posture classification, ROSA as the primary office specific indicator, and the Job Strain Index (JSI) to contextualize distal upper limb force demands. Method scoring and interpretation were supported using standard calculators (e.g., Ergonautas) and documented with photographic evidence.

5. RESULTS

Workstation geometry was generally acceptable in nominal dimensions (desk height approximately 73 cm, within common seated-office ranges), but the functional configuration was not matched to the user-task interaction. The workstation operated as a laptop-dominant setup with the screen substantially below eye level and integrated input devices, which constrained neutral shoulder, elbow, wrist, and cervical posture and favored sustained forward-head posture (Figure 1).

Environmental measurements showed acceptable thermal (23.5 °C) and noise (~49.4 dB) conditions for office work, but a critical illuminance deficit (~85 lx at the work plane vs. 300 lx criterion for administrative tasks), equivalent to roughly a 70% shortfall. This combination is ergonomically relevant because inadequate lighting can intensify visual demand and fatigue, thereby reinforcing compensatory postures during computer work (Khajeh et al., 2023).



Figure 1. Observed workstation posture and setup; lighting was measured at ~85 lx on the work plane (below criterion). (Source: Authors.)

Risk assessment results converged on the need for intervention across complementary methods, strengthening the interpretation that the problem was systemic rather than isolated to a single body region or single scoring approach. Figure 2 summarizes BRIEF™ results with a high-risk profile across the evaluated sequence.

RULA™ yielded a score of 7 (Action Level 4), indicating that investigation and changes should be implemented immediately (Figure 3). This result is consistent with the observed sustained neck flexion, shoulder elevation/flexion asymmetry, wrist extension/flexion, and unsupported lower-limb posture during, and aligns with the pattern commonly reported in office-administration studies where RULA identifies the need for prompt corrective action in computer-based work (Fajria & Ismiyah, 2024).

Job Identification
↓
Critical Tasks and postures observation
↓
Body Segment Assessment Hands–Wrists (Both present Extension/Flexion) Elbows (Both fully extended) Shoulders (Only the right presents posture behind the neck and flexion $\geq 40^\circ$) Neck (Bent $\geq 30^\circ$) Back (Bent $\geq 30^\circ$ with support) Legs (Without support)
↓
Scoring Posture – Force – Duration – Frequency
↓
Conversion factor Σ segments = 65
↓
Physical pressure and additional factors Pressure = 8
↓
Exposure multiplier 20–40 h = 1
↓
Final Risk level 73 → VERY HIGH RISK

Figure 2. BRIEF™ Results. Note: Color codification — Blue: Context and Observation; Yellow: evaluation; Orange: Risk integration; Red: Very High Risk.

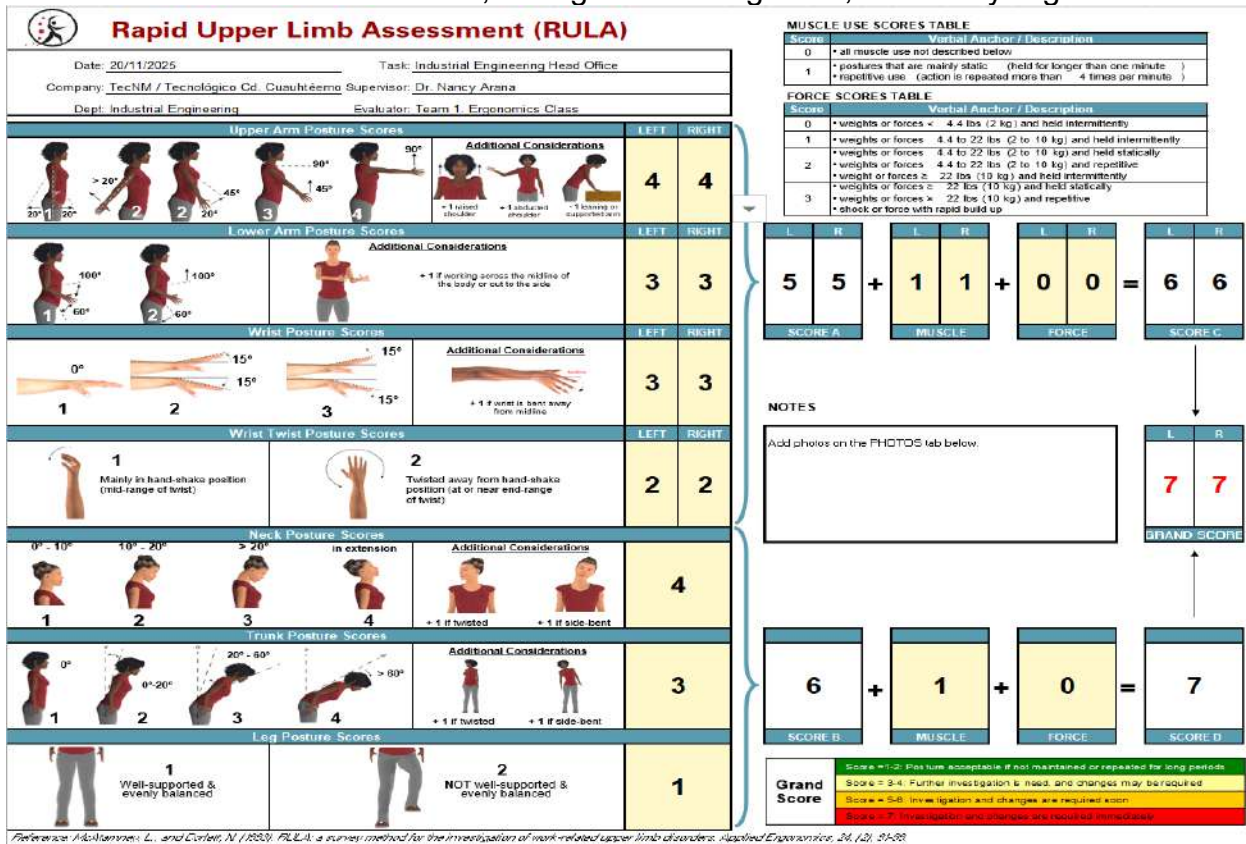


Figure 3. RULA™ Results

LEST indicated elevated work-condition concerns driven mainly by the physical environment (especially lighting) (Figure 4), while OWAS classified the posture in category 2, suggesting corrective action in the near term. Together, these outputs complement RULA by showing that the risk is not only postural but also conditioned by the workstation environment and task organization.

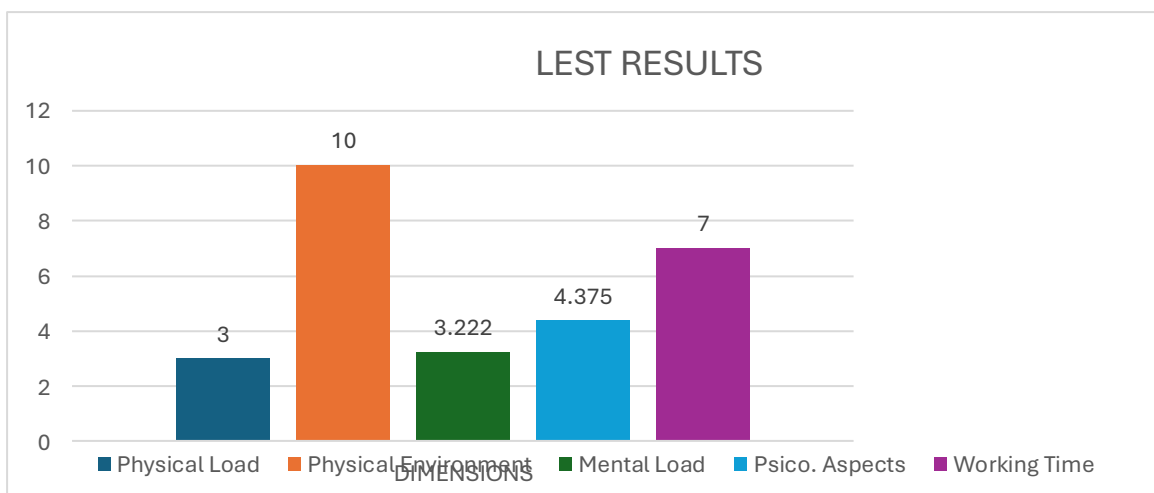


Figure 4. LEST assessment output highlighting physical-environmental concerns.

ROSA, selected as the principal office-specific method because it explicitly evaluates chair, screen/phone, and keyboard/mouse interactions, produced a final score of 8 (very high risk; prompt intervention required) (Figure 5). The dominant drivers were excessive seat height relative to the user, low laptop screen height, and peripheral misalignment. This is especially important because ROSA is designed for office settings and captures interactions with peripherals that generic postural tools may not fully represent; prior research also supports its usefulness for identifying and quantifying changes after ergonomic intervention (de Barros et al., 2022).

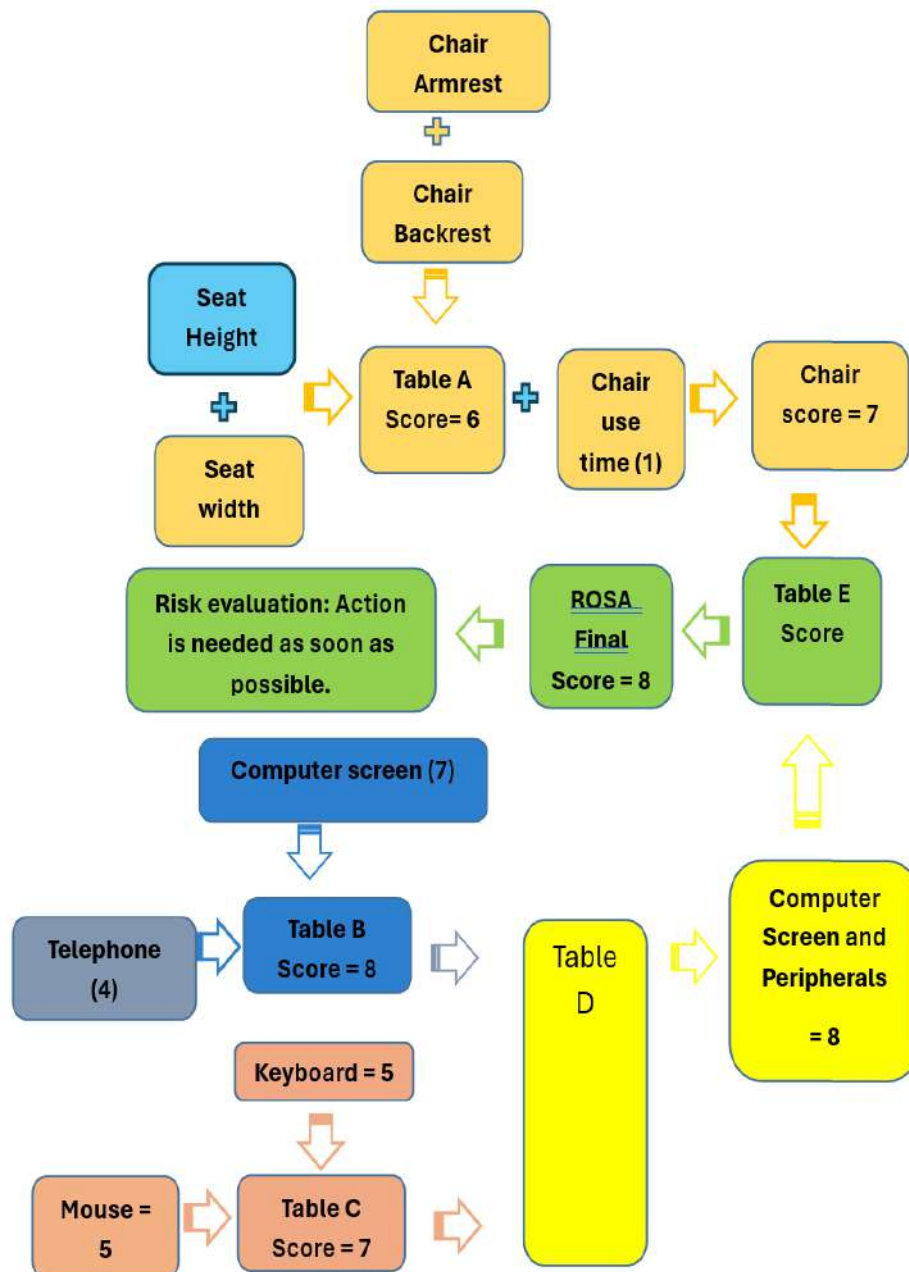


Figure 5. ROSA results (final score 8; very high risk).

In contrast, JSI was 1.5, supporting the interpretation that high forceful hand exertion was not the primary hazard mechanism in this workstation. The risk profile was dominated by static postural loading, visual demand, and workstation-component mismatch, which justifies prioritizing configuration redesign over force-focused controls.

Table 1 summarizes environmental measurements and compliance. The pattern is technically relevant for intervention prioritization: temperature and noise did not indicate urgent correction, whereas illuminance represented the main environmental nonconformity and likely interacted with postural risk and visual strain.

Table 1. Environmental measurements and compliance summary

PARAMETER	MEASURED VALUE	REFERENCE CRITERION	INTERPRETATION
Illuminance (work plane)	85 lx	300 lx (admin tasks)	Critical deficiency (~70% below criterion).
Ambient temperature	23.5 °C	23-26°C (office comfort band)	Within comfort range
Noise level (average)	49.4 dB	<55 dB recommended for concentration	Safe for hearing; potential distractors

Redesign recommendations targeted the identified root causes using standards-oriented, low-cost controls with high implementation feasibility in a higher-education administrative context, where budget constraints, non-adjustable legacy furniture, and shared or fixed workstations often limit full replacement strategies:

- a) Replacing or readjusting seating and adding lumbar support via the design and fabrication of a proposed portable cushion concept aimed at improving pelvic support and lumbar posture (Figure 6).



Figure 6. Adaptive ergonomic seat, design and fabricated by researchers implemented in the man-machine system for postural improvement. (Source: researchers.)

- b) Elevating the laptop screen to the user's line of sight and adding an external keyboard (split/ergonomic) and vertical mouse to restore more neutral neck and upper-limb alignment. This combination addresses the root constraint of laptop-only work by decoupling display height from keyboard position, a recurrent source of office postural mismatch highlighted in office ergonomics literature.
- c) Correcting illuminance with a neutral task light (~4000 K) to provide the missing ~215 lx at the work plane while minimizing screen glare. In practical terms, this measure complements the prototype and peripheral adjustments by reducing visual strain and the tendency to lean forward to improve screen visibility. Based on the identified ROSA drivers and on evidence that workstation adjustment can produce meaningful reductions in ROSA scores (including large changes in chair-related components) (de Barros et al., 2022), the integrated implementation of these measures was projected to reduce the ROSA score from 8 (very high risk) to approximately 3-4 (low to moderate risk). This projection should be interpreted as an evidence-informed estimate pending post-intervention reassessment.

6. CONCLUSIONS

This case study demonstrates that an acceptable office workstation can still present high ergonomic risk when the configuration is mismatched to the task and user. The most critical deficiency was inadequate illuminance, which likely contributed to visual fatigue and to compensatory postural strategies. Triangulating multiple assessment tools was valuable: office-specific ROSA and general postural tools (RULA/OWAS/LEST) consistently indicated interventions, while JSI clarified that forceful hand demands were not the primary driver of risk. The redesign proposal emphasizes low-cost, high-impact controls (screen elevation, peripheral alignment, seating support, and task lighting) that are feasible to implement and can be justified economically compared with potential costs related to discomfort, absenteeism, or long-term musculoskeletal disorders.

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IMPROVING OPERATIONAL EFFICIENCY THROUGH ERGONOMIC ASSESSMENT AND PROCESS OPTIMIZATION IN THE ELECTRONICS INDUSTRY

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Resumen El presente estudio tuvo como objetivo evaluar los factores ergonómicos y operativos asociados a los tiempos y movimientos en celdas de producción dentro de una empresa del sector electrónico, con la finalidad de mejorar la eficiencia productiva y las condiciones laborales. Se desarrolló una investigación aplicada de tipo descriptivo, mediante la implementación de herramientas de ingeniería industrial como estudio de tiempos, diagrama de flujo, diagrama de Ishikawa, metodología 5S y el método RULA para evaluación ergonómica. Los resultados evidenciaron la existencia de movimientos innecesarios, posturas inadecuadas y deficiencias en la distribución del área de trabajo, lo que impactaba negativamente en la productividad. Tras la implementación de mejoras, se logró reducir el tiempo de ciclo de 331 minutos a 253 minutos, así como un incremento del 30% en la producción diaria. Asimismo, se realizaron propuestas para disminuir el nivel de riesgo ergonómico. Se concluye que la integración de herramientas de mejora continua y ergonomía permite optimizar procesos productivos y mejorar el bienestar de los trabajadores.

Palabras clave: Estudio de tiempos y movimientos, RULA, productividad, mejora continua

Relevancia para la ergonomía: este estudio contribuye al análisis aplicado de la ergonomía en entornos industriales, demostrando cómo la intervención ergonómica puede reducir riesgos musculoesqueléticos y mejorar la eficiencia operativa en sistemas productivos.

Abstract: The objective of this study was to evaluate the ergonomic and operational factors associated with time and motion in production cells within a company in the electronics sector, with the aim of improving production efficiency and working conditions. A descriptive applied research study was conducted using industrial engineering tools such as time studies, flowcharts, Ishikawa diagrams, the 5S methodology, and the RULA method for ergonomic evaluation. The results revealed

the existence of unnecessary movements, improper postures, and deficiencies in the layout of the work area, which negatively impacted productivity. Following the implementation of improvements, the cycle time was reduced from 331 minutes to 253 minutes, and daily production increased by 30%. Furthermore, the ergonomic risk level decreased significantly, dropping from high to low. It is concluded that the integration of continuous improvement and ergonomic tools enables the optimization of production processes and improves worker well-being.

Keywords: ergonomics, time and motion, RULA, productivity, continuous improvement.

Relevance to Ergonomics: This study contributes to the applied analysis of ergonomics in industrial settings, demonstrating how ergonomic intervention can reduce musculoskeletal risks and improve operational efficiency in production systems.

1. INTRODUCTION

Operational efficiency and ergonomic safety are critical factors for competitiveness in today's manufacturing industry. In this context, the integration of principles from industrial engineering and ergonomics has gained prominence as a strategy for optimizing production processes and reducing workplace risks. Time and motion studies help identify activities that do not add value, while ergonomics analyzes the interaction between the worker and their environment, with the goal of adapting working conditions to human capabilities (Niebel & Freivalds, 2014).

Various studies have shown that industrial environments with highly repetitive tasks and manual handling present a high incidence of musculoskeletal disorders (MSDs), which represent one of the leading causes of work absenteeism and reduced productivity globally (Balderas-López et al., 2019). These disorders are closely linked to risk factors such as forced postures, repetitive movements, and excessive exertion—conditions commonly found in production cells (Urrejola-Contreras et al., 2021).

In this regard, the Rapid Upper Limb Assessment (RULA) method has established itself as a widely used tool for assessing ergonomic risk in industrial tasks, enabling the identification of risk levels and the establishment of intervention priorities (Pincay Vera et al., 2021). Recent studies have confirmed the validity of this method for the early detection of poor ergonomic conditions and their impact on occupational health (Halek et al., 2025).

Furthermore, the implementation of continuous improvement tools such as Lean Manufacturing and the 5S methodology has proven effective in eliminating waste, improving workflow, and increasing productivity. According to Gupta and Jain (2015), eliminating activities that do not add value (*muda*) allows for process optimization and reduced cycle times, contributing to greater operational efficiency.

Likewise, recent research highlights that integrating ergonomics with continuous improvement approaches not only positively impacts productivity but also improves

working conditions and reduces the physical strain on workers (González-Alonso et al., 2025). This comprehensive approach is particularly relevant in industrial settings where pressure to increase production can lead to unfavorable working conditions.

Despite these advances, many organizations still lack sufficient integration between ergonomic analysis and process optimization, which represents a gap in both industrial practice and the scientific literature. In particular, production cells in the electronics sector face issues related to long cycle times, unnecessary movements, and poor ergonomic conditions, all of which negatively impact the performance of the production system.

2. OBJECTIVES

Improve cycle times and work movements in production cells by applying continuous improvement tools and ergonomic assessments.

3. METHODOLOGY

This study was conducted using a descriptive-applied quantitative approach, with the aim of analyzing and optimizing times, movements, and ergonomic conditions in a production cell in the electronics sector. The study was conducted in a production cell belonging to a company in the electronics sector. The unit of analysis consisted of the operators directly involved in the production process, as well as the activities that make up the cell's workflow.

The following techniques were used to collect and analyze data:

- Time study:
- Flowchart:
- Ishikawa diagram:
- 5S methodology:
- RULA method

Independent variable:

Implementation of continuous improvement tools and ergonomic assessment (5S, layout redesign, RULA).

Dependent variables:

- Cycle time
- Productivity
- Ergonomic risk level
- Working conditions

The research was conducted in five main stages:

1. Initial assessment: A detailed analysis of the production process was conducted through direct observation and time studies to identify inefficiencies, unnecessary activities, and problems in work organization.
2. Ergonomic assessment: The RULA method was applied to evaluate operators' postures during task execution, determining the level of ergonomic risk and critical areas for intervention.
3. Identification of waste: Using flowcharts and Ishikawa diagrams, the main sources of waste (muda) were identified, including unnecessary movements, downtime, and deficiencies in the layout of the area.
4. Implementation of improvements: Corrective actions were designed and implemented based on the 5S methodology and the redesign of the workstation layout, with the aim of improving organization, facilitating workflow, and reducing unnecessary effort.
5. Validation of results: A new time study and an ergonomic reevaluation were conducted after the intervention, comparing the results with the initial situation to measure the impact of the implemented improvements in terms of productivity and reduction of ergonomic risk.

4. RESULTS

4.1 Process Flowchart Improvement

The previous flowchart showed a bottleneck in the oven curing assembly process, specifically in the verification of the disc temperature. Although there were no obvious problems, this bottleneck could lead to errors and delays. A duplication of tasks was identified, meaning that tasks already completed were being repeated. This resulted in a waste of time and resources, as shown in Figure 1.



2).



4.3 Ishikawa Diagram

Based on the research and observations conducted, which identified poor posture and excessively long production times as problems, an Ishikawa diagram was developed to identify the root causes; see Figure 3.

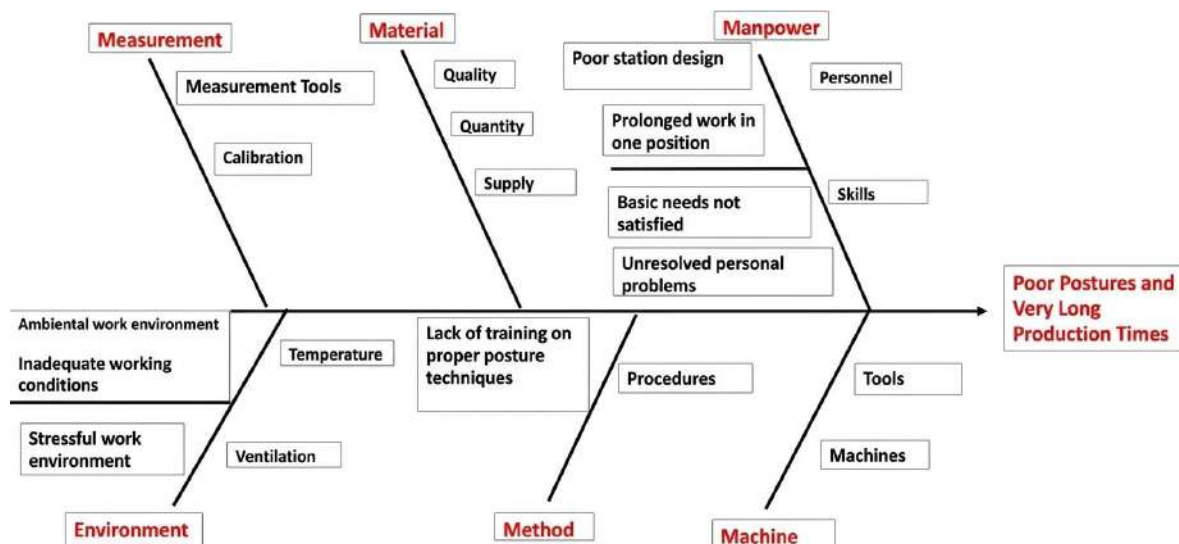


Figure 3. Ishikawa Diagram

4.4 Gathering Feedback from Staff:

To identify opportunities for improvement in the production cells, a survey was administered to the operators. Forty percent of the workers perceive the current layout as confusing and disorganized, while 30% consider it acceptable but in need of improvement, highlighting the need to reorganize the work area. The main challenges identified relate to defective equipment (45%) and communication deficiencies (35%), which directly impact process efficiency.

The main proposals for improvement focused on increasing the availability of tools and equipment (30%), as well as improving environmental conditions and the organization of the area (25% each). Figure 4 shows the resulting graphs.

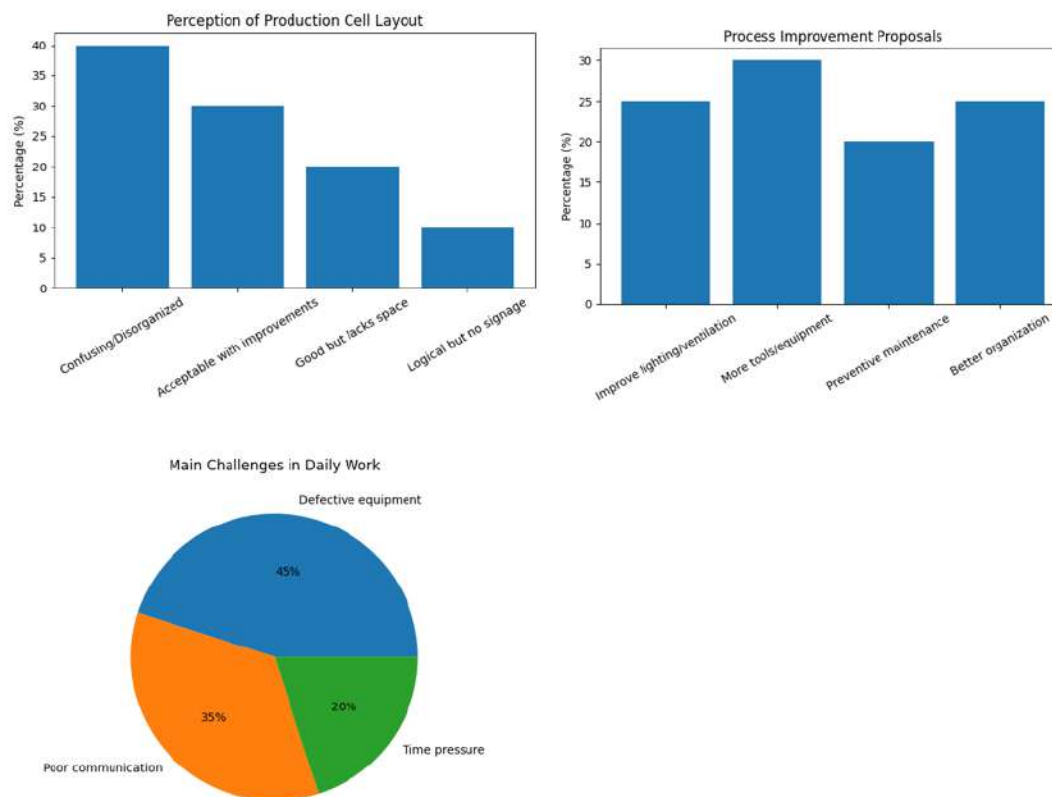


Figure 4. Charts showing staff feedback results

4.5 Implementation of 5S

The implementation of 5S in an Accudisc production cell was a systematic process aimed at improving efficiency, productivity, and quality in the workplace. Table 1 shows some examples of the implementation.

Table 1. Examples of actions implemented for the 5S program

Tool/Object	Initial Condition	5S Action	Final Location
Cutting matrix	Scattered across the work area	Sorting and organization	Labeled tool cabinet
Assembly tool	Stored in a disorganized drawer	Organization and labeling	Labeled toolbox
Precision caliper	Placed on a disorganized shelf	Sorting and organization	Designated labeled shelf
Inspection magnifier	Scattered across the work area	Organization and labeling	Labeled toolbox
Adjustment tool	Stored in a disorganized drawer	Sorting and organization	Labeled tool cabinet
Thickness gauge	Placed on a disorganized shelf	Organization and labeling	Designated labeled shelf
Cleaning tools	Scattered across the work area	Sorting and organization	Labeled toolbox

4.6 Assessment Using the RULA Method



Figure 5. Analyzed work posture

A. Análisis de brazo, antebrazo y muñeca

Paso 1: Localizar la posición del brazo

Si el hombro está elevado: +1
Si el brazo está abducido (alejado del cuerpo): +1
Si el brazo está apoyado o sostenido: -1

Puntuación brazo: 3

Paso 2: Localizar la posición del antebrazo

Si el antebrazo cruza la línea media del cuerpo: +1
Si el brazo está de la línea del cuerpo: +1

Puntuación antebrazo: 3

Paso 3: Localizar la posición de la muñeca

Si la muñeca está doblada por la línea media: +1

Puntuación muñeca: 3

Paso 4: Giro de muñeca

Si la muñeca está en el rango medio de giro: +1
Si la muñeca está girada por encima o por debajo del rango: +2

Puntuación giro de muñeca: 2

Paso 5: Localizar puntuación postural en Tabla A

Utilizar valores de pasos 1, 2, 3 y 4 para localizar puntuación postural en Tabla A

Puntuación postural A: 5

Paso 6: Anotar puntuación utilización muscular

Si la postura es principalmente estática (p.e. espaldas superiores a 1 min.) o si ocurre repetidamente la acción (4 veces/min. o más): +1

Puntuación muscular: 1

Paso 7: Anotar puntuación de la fuerza / Carga

Si carga o esfuerzo < 2 Kg. intermitente: +0
Si se da 2 a 10 Kg. intermitente: +1
Si se da 2 a 10 Kg. estática o repetitiva: +2
Si se usa carga > 10 Kg. o vibrante o súbita: +3

Puntuación fuerza/carga: 0

Paso 8: Localizar fila en Tabla C

Ingresar a Tabla C con la suma de los pasos 5, 6 y 7

Puntuación final muñeca, antebrazo y brazo: 6

Puntuación Final: 7

Referencias:

Observador: _____ Firma: _____

Puntuación Final: 1 ó 2: Aceptable; 3 ó 4: Ampliar el estudio; 5 ó 6: Ampliar el estudio y modificar pronto; 7: estudiar y modificar inmediatamente

Figure 6. RULA Method Evaluation

A score of 7 was obtained, indicating that the case should be reviewed and modified immediately. The following are some recommended modifications:

- Adjust the height of the work table to the operator's elbow height (approx. 90–105 cm)
- Redesign access to the cabinet: open it sideways or tilt the workstation to avoid cervical flexion
- Evaluate the use of a chest support/armrest to reduce strain on the trunk and neck
- Implement task rotation to limit continuous exposure to this posture
- Consider a lift table or adjustable ergonomic workstation
- Provide adequate breaks: Ensure that workers have regular and sufficient breaks to recover from muscle fatigue.
- Train workers: Provide training to workers on safe and efficient work techniques to reduce the risk of MSDs.
- Supervise and monitor: Supervise and monitor the task and workers to ensure that corrective actions are being implemented and the risk of MSDs is being reduced.

4.7 Work Area Rearrangement

The workspace lacked a logical layout because the operators were working and handling all tools with their left hands; this meant that all movements had to be performed in reverse. Figure 7 shows the previous layout of the work cell.

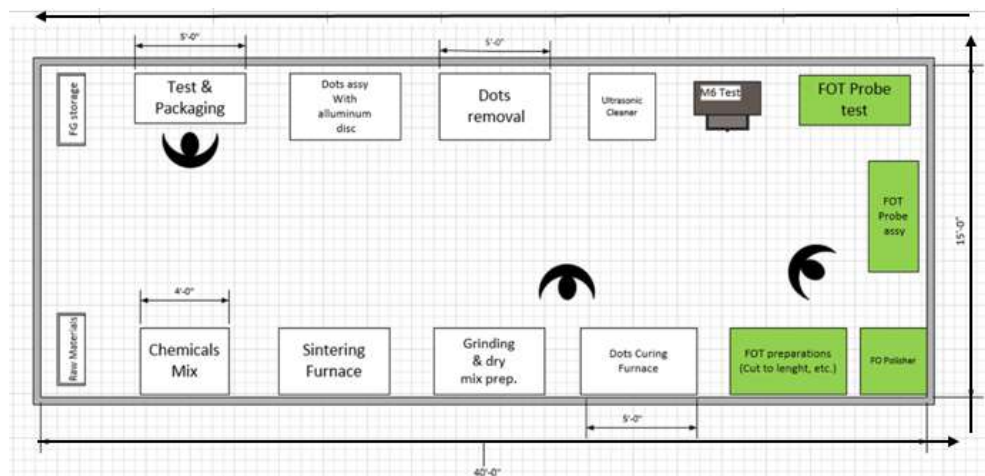


Figure 7. Previous layout

It was designed to reduce the number of movements and actions required to complete tasks, and to improve efficiency and productivity in the production process.

The optimized workflow is as follows:

1. The operator receives the object at the workstation.
2. The operator processes the object with their right hand.

3. The operator passes the object to the next workstation with their right hand.

The changes made to the optimized workstation were as follows:

- The workflow was reversed, so that operators now pass the object with their right hand to the next workstation.
- Tools and materials were reorganized to reduce the movements and actions required to complete tasks.
- Lighting and ventilation at the workstation were improved to reduce operator fatigue and stress.
- The design of the optimized workstation offers several benefits, including:
 - Reduced operator fatigue and stress.
 - Increased efficiency and productivity in the production process.
 - Improved product quality, as shown in Figure 8.

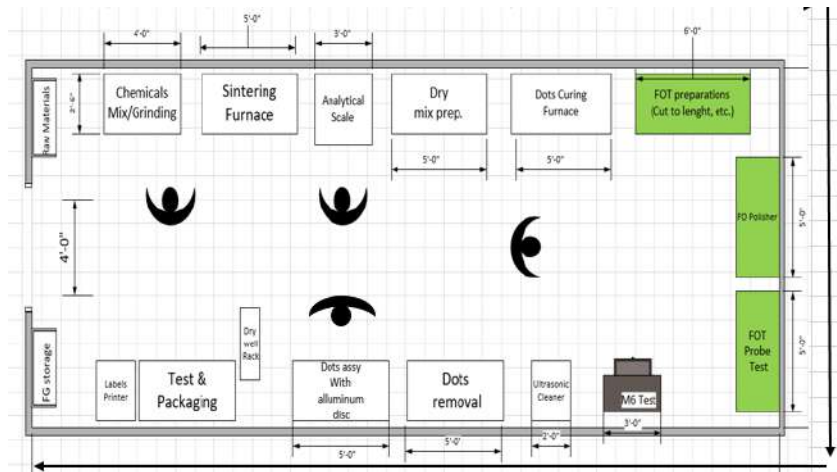


Figure 8. Current layout

4.8. Improvements in Production Times

The first-time study was conducted based on the original configuration of the production cell, resulting in a standard time of 331.86 minutes for a daily production cycle, producing the following quantity: $0.117 \text{ units/minute} \times 331.86 \text{ minutes} = 38$ units; approximately 38 AccuDisc units were produced in 331.86 minutes, The records are shown in Table 1.

Table 2. Initial time study

TASK (ACTIVITY)	T1	T3	T4	T5	T6	T7	T8	T9	T10	AVERAGE TIME	RATING	NORMAL TIME (average time * rating)	TYPE TIME (normal time * (1 + allowance))
PREPARATION	11.24	12.36	15.40	18.33	20.20	24.10	29.40	31.40	33.05	21.72	1.1	23.89	27.48
PREPARATION OF DRY MIX WITH EPOXY	15.15	17.25	20.56	23.10	24.26	26.34	31.43	37.22	44.17	26.61	1.2	31.93	36.72
APPLICATION OF THE MIX ONTO THE MOLD	28.50	28.25	28.59	34.05	39.12	40.23	43.26	56.31	64.33	40.29	1	40.29	46.34
CURING DOTS IN BATCHES	26.40	26.55	27.10	27.45	28.33	28.45	29.56	30.12	31.56	28.39	0.9	25.55	29.38
REMOVAL OF DOTS FROM THE MOLDING FIXTURE	9.24	9.31	9.40	10.30	10.30	11.10	11.40	12.19	12.55	10.67	1	10.67	12.27
CLEANING OF ALUMINUM DISCS	13.33	13.56	14.22	14.43	14.55	15.34	15.43	16.22	17.17	14.92	1	14.92	17.16
ASSEMBLY OF DOTS AND ALUMINUM DISC	19.50	20.25	21.59	22.05	22.12	22.59	23.36	23.51	24.27	22.13	1.2	26.55	30.53
OVEN-CURED DOTS ASSEMBLY	56.63	58.56	61.34	64.56	75.56	72.23	60.32	62.04	61.41	63.59	1.4	89.03	102.39
TEMPERATURE VERIFICATION (TEST)	10.24	10.39	10.43	10.31	10.57	11.10	10.46	11.19	9.55	10.47	1	10.47	12.04
RECOVER ALUMINUM DISC ASSIGNMENT AND PACKAGING	4.32	5.01	5.16	4.59	4.47	5.33	5.27	5.47	5.51	5.01	1	5.01	5.77
STANDARD TIME	11.43	10.16	8.56	11.56	10.1	9.19	11.45	10.36	9.37	10.24	1	10.24	11.78
													331.86

Factors that were taken into account:

SUPPLEMENTS	%			Rating		
BASIC FATIGUE	4%	0.04		Slow	<100%	<1
PERSONAL	3%	0.03		Normal	100%	1
ENVIRONMENT	2%	0.02		Fast	>100%	>1
POOR POSTURE	6%	0.06				
	15%	0.15				

In the previous time study, several factors were identified that were affecting the process's productivity. However, after implementing a series of improvements—including the design of an optimal workstation and pre-training for operators—a new time study was conducted to assess the impact of these improvements on the process.

The new time study revealed that, with the redesigned workstation and prior training, the time required to complete the process was significantly reduced. This was because the redesigned workstation allowed for greater efficiency in the workflow, reducing wait times and enabling operators to work more effectively.

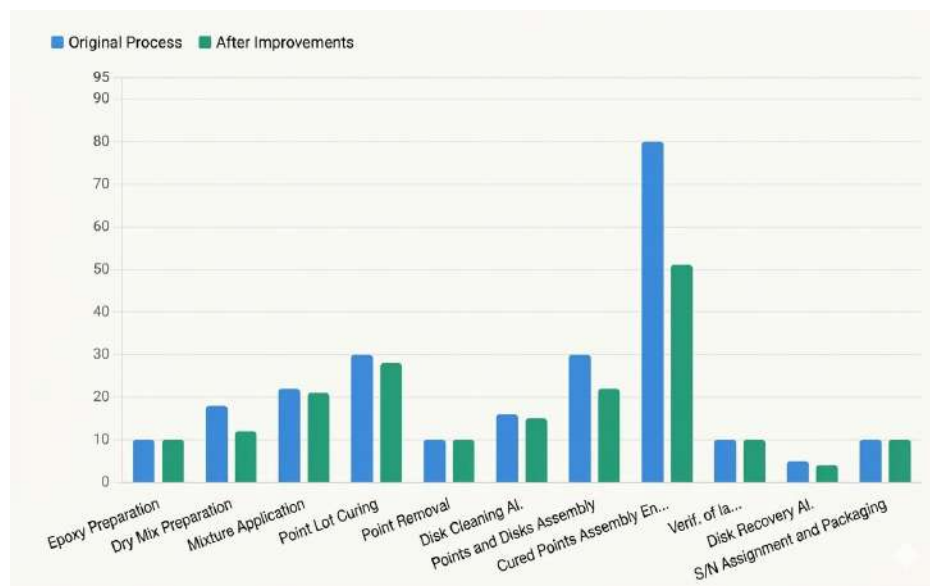


Figure 9. Averages after the improvements were implemented

Tabla 3. Improvements by activity

Activity	Implemented Improvement	Previous Time (min)	Current Time (min)	Reduction
Assembly of points and aluminum disc	Training in proper assembly + quality procedures	27	22	-18%
Curing point assembly	More efficient curing system	64	50	-22%
Temperature verification (testing)	More efficient verification system	14	10	-28%

Table 4. Impact on daily production (9-hour workday / 540 min)

Scenario	Time per Batch (min)	Units per Batch	Daily Production (units)
Original process	331	38	62
After improvements	253	38	81
Increase in daily production			
+19 unidades (+31%)			
Reduction in time per batch			
78 min (-24%)			

5. DISCUSSION/CONCLUSIONS

The results show that integrating methods engineering and ergonomics tools improves both productivity and working conditions. In particular, cycle time was reduced by 23.6% and production increased by 30%, confirming the effectiveness of the intervention.

From an ergonomic standpoint, proposals were made to reduce risk, indicating a significant improvement in operators' postures and safety. This supports findings in the literature, which establish that reducing forced postures and repetitive movements decreases the likelihood of musculoskeletal disorders.

In addition, the application of Lean tools, such as 5S and the elimination of unnecessary activities, improved workflow and reduced non-value-added movements. The reorganization of the workspace facilitated tasks and reduced travel, contributing to a more efficient operation.

Overall, the results confirm that ergonomics not only improves worker health but also has a direct impact on productivity. This reinforces the idea that ergonomics should be considered a strategic element within production systems.

However, the study has limitations, such as the analysis of a single production cell and the exclusive use of the RULA method. Even so, the findings suggest that simple interventions based on ergonomics and continuous improvement can yield significant benefits in both operational performance and workplace well-being.

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ERGONOMIC ANALYSIS IN THE QUALITY LABORATORY OF A CONCRETE MATERIALS COMPANY TO IMPROVE WORKER PRODUCTIVITY

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Resumen: La industria de la construcción en México, particularmente en el sector de producción de concreto, presenta altos índices de riesgos ergonómicos debido a la naturaleza física de sus procesos. En el laboratorio de calidad, la extracción y ensayo de muestras para pruebas de consistencia y resistencia exigen una manipulación constante de materiales pesados. Se identificó que los operarios realizan tareas críticas al ras del suelo, lo que deriva en posturas forzadas, flexiones de tronco extremas y agachamientos repetitivos, incrementando la probabilidad de desarrollar lesiones musculoesqueléticas. El objetivo es Analizar y diseñar las condiciones ergonómicas en la estación de trabajo del laboratorio de calidad para mitigar la exposición a riesgos biomecánicos. La investigación se basó en un diagnóstico de campo aplicando el método RULA (*Rapid Upper Limb Assessment*) para cuantificar el nivel de riesgo por carga postural. Complementariamente, se utilizó el cuestionario de Corlett y Bishop para mapear las zonas de mayor incomodidad reportadas por los trabajadores. Con ello se espera que el análisis permitió determinar niveles de actuación que exigen cambios urgentes en el diseño del puesto, centrando la propuesta en la elevación de las superficies de trabajo y la optimización de los flujos de manipulación de carga. Con la implementación de estas mejoras no solo previene enfermedades de trabajo, sino que asegura la precisión en los procesos de control de calidad bajo condiciones de seguridad y salud ocupacional.

Palabras claves: Método RULA, Diseño ergonómico, DTA, productora de concreto.

Relevancia para la ergonomía: La ergonomía es la interacción entre los seres humanos y otros elementos de un sistema. Este estudio aporta información que contribuye a la mejora de las condiciones de trabajo del sector concretos.

Abstract: The construction industry in Mexico, particularly in the concrete production sector, presents high rates of ergonomic risks due to the physical nature of its processes. In the quality control laboratory, the extraction and testing of samples for

consistency and strength tests require constant handling of heavy materials. It was identified that operators perform critical tasks at ground level, resulting in awkward postures, extreme trunk flexion, and repetitive bending, increasing the likelihood of developing musculoskeletal injuries. The objective is to analyze and design ergonomic conditions at the quality control laboratory workstation to mitigate exposure to biomechanical risks. The research was based on a field assessment using the Rapid Upper Limb Assessment (RULA) method to quantify the level of risk from postural load. Additionally, the Corlett and Bishop questionnaire was used to map the areas of greatest discomfort reported by the workers. The analysis is expected to identify areas requiring urgent changes to the workstation design, focusing on raising work surfaces and optimizing material handling flows. Implementing these improvements will not only prevent work-related illnesses but also ensure accuracy in quality control processes under safe and healthy occupational conditions.

Keywords: RULA method, Ergonomic design, DTA, concrete producer.

Relevance to ergonomics: Ergonomics is the interaction between humans and other elements of a system. This study provides information that contributes to improving working conditions in the concrete sector.

1. INTRODUCTION

In the construction industry, the increase in concrete production has intensified the physical demands of quality control processes. Globally, the International Labour Organization (ILO) indicates that musculoskeletal disorders (MSDs) account for more than 60% of occupational illnesses; in Mexico, the Mexican Social Security Institute (IMSS) reports that these conditions constitute 24.7% of registered cases, impacting both worker health and organizational productivity through temporary or permanent disabilities. The quality control area of the company under study is characterized by tasks with high biomechanical demands, such as handling molds and tools, and collecting samples. The critical factor identified is the placement of materials at ground level, which forces personnel to adopt repetitive trunk flexion and bending postures during long shifts ranging from 10 to 17 continuous hours.

A comprehensive ergonomic assessment will be conducted using the RULA method to evaluate postural load and the Corlett and Bishop Map to identify areas of discomfort and physical fatigue. The study focused on analyzing the interaction between the operator and their workstation under real operating conditions. The results confirm a direct correlation between inadequate ergonomic conditions and the presence of pain symptoms in workers. It was determined that prolonged exposure to awkward postures and extended standing generate risk levels that require immediate intervention. The study concludes that an ergonomic redesign of the workstation is necessary to optimize material handling heights and reduce physical effort, thus ensuring operational sustainability and the well-being of the workforce.

2. OBJECTIVE

Analyze and evaluate the biomechanical conditions in the workstation of the quality control laboratory of the Concrete company, through the application of ergonomic evaluation methods, to develop a redesign proposal that mitigates the risk of musculoskeletal disorders.

3. METHODOLOGY

1. Conduct a diagnostic assessment of the work process in the quality control laboratory by observing the work area, identifying the activities performed by the operator, as well as the workplace conditions that may affect the worker's health and safety. This assessment will be based on the identification of Mexican Official Standards (NOMs) and ergonomic principles.

2. Identify the risk factors present in the quality control laboratory, such as awkward postures, materials handling, and repetitive tasks. Ergonomic assessment methods such as RULA will be applied to detect potential musculoskeletal disorders related to work activities.

3. Design ergonomic and safety conditions in the quality control laboratory to ensure improved productivity.

4. RESULTS

During the analysis at the quality control station, a flowchart was created to identify the activities and responsibilities of each worker. It was found that the tasks performed by the operator involve inadequate ergonomic conditions, which pose a significant risk to his health. While performing tasks, the worker adopts forced postures, primarily flexion of the upper trunk and neck ($>60^\circ$), as well as repetitive bending to handle materials at floor level, which creates a very HIGH risk.

The RULA method was applied because it is highly effective for assessing static and forced postures of the upper extremities. A score of 7 was obtained, indicating the need for immediate intervention in working conditions.

The joint angle analysis principle was applied to determine that trunk flexion exceeded 60° during tasks involving handling objects at ground level. The lab technician's discomfort map indicated pain in the shoulders, back, and feet; the diagnosis indicated that he spends most of his time standing and exposed to noise.

The assessment focused on working hours, and the workplace fatigue survey revealed that laboratory technicians work 16–17 hours a day and do not have a fixed schedule. This failure to comply with the principle of work scheduling represents a VERY HIGH risk under NOM-035-STPS-2018, as it increases mental fatigue and reduces the opportunity to take active breaks to break up static postures.

Furthermore, the lack of control over noise (NOM-011-STPS-2001) and vibrations (NOM-024-STPS-2001) creates a sensory overload that can cause additional fatigue in the laboratory technician.

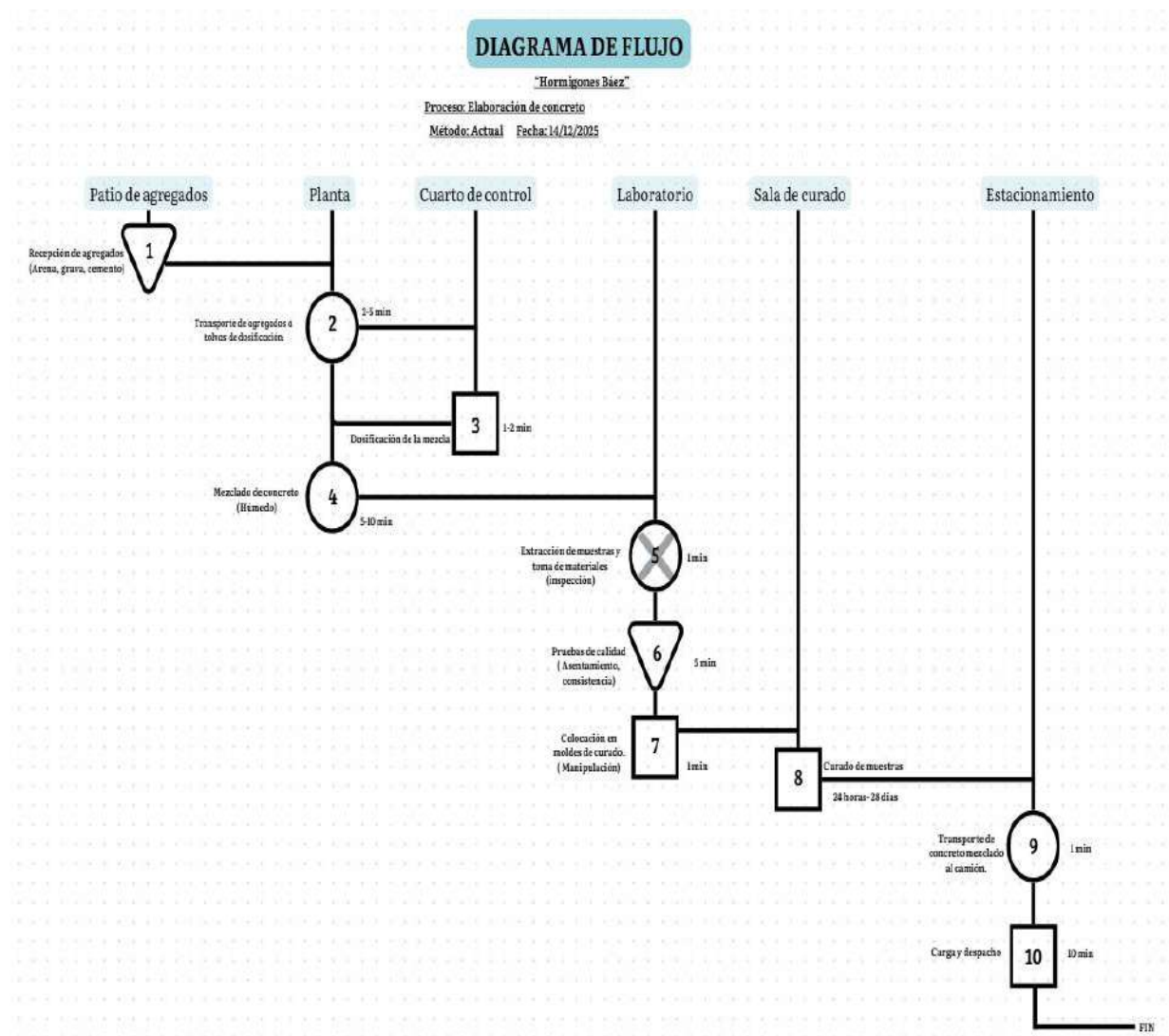


Figure 1. Operations diagram



Figure 2. Concrete quality control station

Table 1. Identification of Official Mexican Standards of the STPS.

List of official Mexican Standards applied to the production process of the company			
Company: Báez Hormigones			
Line of business: Production and supply of concrete for construction			
Date: March 12, 2026			
Standard	Yes	No	Observations
Official Mexican Standard NOM-036-1-STPS-2018, Ergonomic risk factors at work – Manual handling of loads.		X	Workers perform manual handling of materials and tools in inadequate positions, such as bending and lifting from ground level, without proper ergonomic conditions.
Official Mexican Standard NOM-035-STPS-2018, Psychosocial risk factors at work – Identification, analysis and prevention		X	Long working hours and physical workload may contribute to fatigue and stress, without evidence of evaluation or preventive measures.
Official Mexican Standard NOM-001-STPS-2008, Buildings, premises, facilities and areas in workplaces – Safety conditions	X		The work area presents acceptable general conditions; however, improvements are needed in the organization and layout to reduce ergonomic risks.
Official Mexican Standard NOM-024-STPS-2001, Vibrations – Safety and hygiene conditions in the workplace		X	.Equipment used in the area may generate vibrations, and no control measures or preventive maintenance were identified.
Official Mexican Standard NOM-011-STPS-2001, Safety and hygiene conditions in workplaces where noise is generated		X	There is no evidence of noise level measurements or use of hearing protection, exposing workers to potential risk.

Table 2. Ergonomic principles applied to workstation 1

Principles	Remarks
Principle 1: Neutral Posture Maintenance Principle (Physical Ergonomics)	In the laboratory station (RULA 7), this principle is violated due to material handling at ground level, forcing trunk flexion greater than 60°, which generates pain in the middle and lower back. In the control room (RULA 6), the furniture does not allow a 90-90-90 posture, resulting in prolonged static posture and discomfort in the upper, middle, and lower back.

Principle 2: Work Temporal Organization (Organizational and Cognitive Ergonomics)	This principle is not met due to working shifts ranging from 10 to 17 hours without a fixed schedule. This condition prevents proper worker recovery and limits the implementation of active breaks, increasing fatigue associated with RULA 6 and RULA 7 risk levels.
Principle 3: Environmental Comfort and Safety Principles (Environmental Ergonomics)	Lack of noise control (NOM-011) leads to constant worker exposure. Additionally, absence of maintenance and personal protective equipment (NOM-024) increases vibration-related risks. Thermal comfort is also compromised due to lack of temperature monitoring and inadequate protective measures (NOM-015).

During the ergonomic assessment, it was found that the STPS legal framework was rarely applied. Mexican Official Standard NOM-025-STPS-2008 is not applied due to lighting conditions, as the lighting is insufficient for the minimal work performed at the workstation.

Mexican Official Standard NOM-011-STPS-2001, regarding safety and hygiene conditions in workplaces where noise is generated, does not control the decibel level used in the process, exposing workers to levels exceeding 90 decibels during the workday. The Official Mexican Standard NOM-001-STPS-2008 does not provide specific guidelines for the processes carried out in the workshop. The Official Mexican Standard NOM-015-STPS-2001 establishes the appropriate conditions for exposure to temperatures. In the workshop, temperatures range from 42 to 48 degrees, creating an inadequate thermal environment that causes fatigue and mental exhaustion.

4.1. Application of ergonomic evaluation methods in station.

Método R.U.L.A. Hoja de Campo

Puntuación

Tabla A

	1	2	3	4	5	6	7	8	9	10
1	1	2	3	4	5	6	7	8	9	10
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4	4	5	6	7	8	9	10	11	12	13
5	5	6	7	8	9	10	11	12	13	14
6	6	7	8	9	10	11	12	13	14	15
7	7	8	9	10	11	12	13	14	15	16
8	8	9	10	11	12	13	14	15	16	17
9	9	10	11	12	13	14	15	16	17	18
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Tabla B

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4	4	5	6	7	8	9	10	11	12	13
5	5	6	7	8	9	10	11	12	13	14
6	6	7	8	9	10	11	12	13	14	15
7	7	8	9	10	11	12	13	14	15	16
8	8	9	10	11	12	13	14	15	16	17
9	9	10	11	12	13	14	15	16	17	18
10	10	11	12	13	14	15	16	17	18	19

Tabla C

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8	8	9	10	11	12	13	14	15	16	17
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Puntuación Final

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Puntuación por parte de

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Puntuación por parte de

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Puntuación Final

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2	2	3	4	5	6	7	8	9</		

4.2. Design of ergonomic conditions in the work station.

The applicable Mexican Official Standards were analyzed, primarily NOM-036-1-STPS-2018 on the manual handling of loads. Based on this analysis, it was observed that at the quality control station, workers perform tasks that involve improper postures, particularly when handling materials from floor level, which increases the risk of physical problems.

It was also identified that the workstation conditions are suboptimal, as the worker remains standing for long periods, resulting in fatigue. Therefore, it is considered important to improve the work area to make it more comfortable and reduce physical strain. One of the best recommendations is to adjust the height of work surfaces to prevent the worker from having to constantly bend down. This will help make movements less strenuous. These changes aim to reduce the worker's physical strain and prevent long-term discomfort or injuries.

Here is a proposal outlining the improvements you can make within the company.

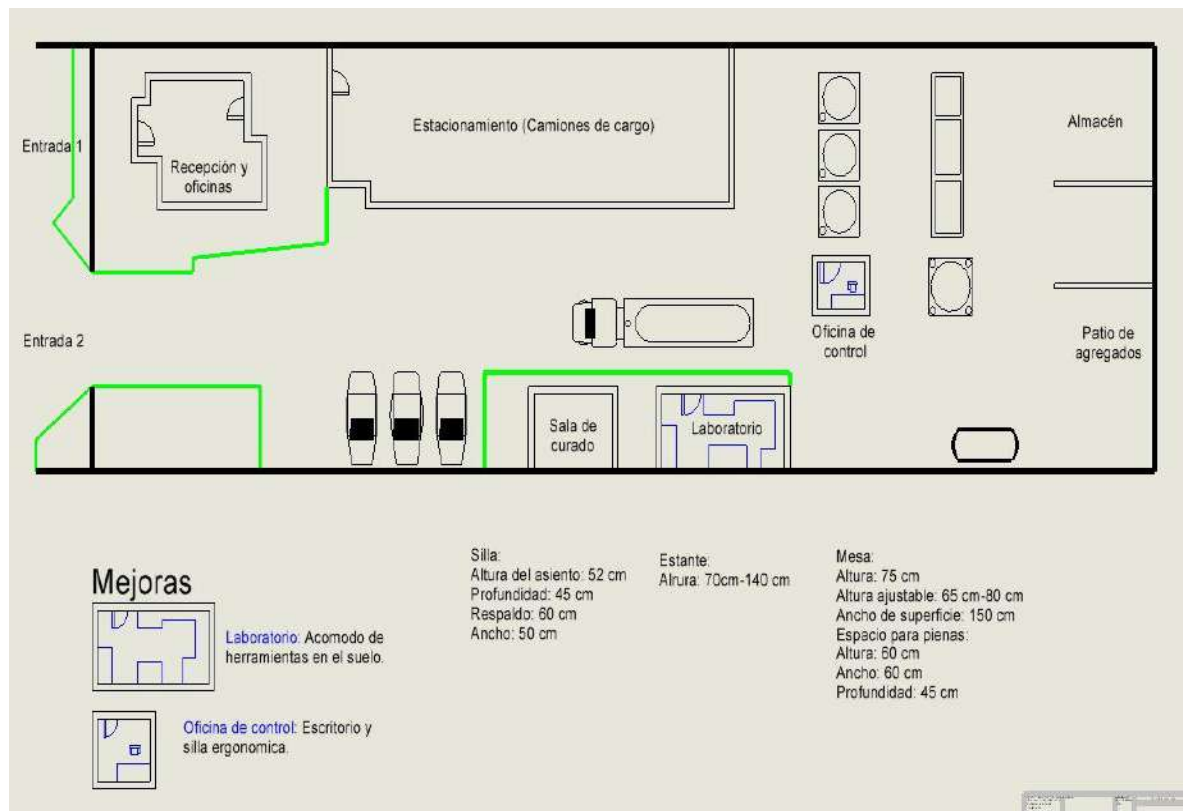


Figure 4. Company layout

5. CONCLUSIONS

The ergonomic analysis identified risks in the quality control laboratory. The operator performs their work using improper movements, as the materials are at floor level, which causes them to repeatedly bend their torso and crouch.

The RULA assessment and the application of ergonomic principles helped identify risk levels. The result was a RULA score of 7, indicating a VERY HIGH risk and the need for changes to the workstation.

The most viable solution is to install shelving and elevated storage platforms so that all materials can be handled between knee and shoulder height, making it more comfortable for the operator. This measure eliminates the forced flexion posture, allowing the lab technician to work in a neutral posture while complying with NOM-036-1-STPS-2018. Additionally, we propose implementing breaks during the workday and fixed schedules to reduce work-related fatigue. We also recommend implementing the use of PPE to prevent exposure to noise.

The benefits of this workplace redesign are significant, as it helps prevent operators from adopting awkward postures, reduces work-related fatigue, and prevents the onset of musculoskeletal injuries. These modifications are expected to improve the laboratory technician's productivity and quality of life.

The ergonomic analysis identified risk factors related to improper posture and repetitive movements during the handling of materials at floor level. It also identified weak compliance with NOMS standards, as the workplace does not meet requirements related to ergonomics, environmental conditions, and work organization.

The ergonomic assessment shows that laboratory technicians are at risk of musculoskeletal injuries, primarily in the back, shoulders, and extremities.

The proposed improvements for the laboratory are based on redesigning the workstation and properly positioning materials. These actions help reduce occupational risks and improve operator performance, leading to higher productivity and a lower probability of injury.

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ERGONOMIC ANALYSIS AND ASSESSMENT OF OCCUPATIONAL RISKS IN GRILLED FOOD PREPARATION PROCESSES.

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Resumen: A nivel global y nacional, los trastornos musculoesqueléticos representan las principales causas de discapacidad laboral en el sector servicios. En México, el Instituto Mexicano del Seguro Social (IMSS) reporta que las patologías de espalda y extremidades superiores derivan en una pérdida significativa de días-hombre. En estado de Sinaloa, el crecimiento de las micro y pequeñas empresas (PyMEs) de preparación de alimentos a la parrilla ha evidenciado una carencia de infraestructura ergonómica, donde las jornadas extensas y las condiciones térmicas extremas. A nivel local, este fenómeno se traduce en una baja productividad y un deterioro progresivo de la salud del capital humano en establecimientos de comida rápida. El objetivo es evaluar los factores de riesgo ergonómico en las estaciones de trabajo de una empresa de alimentos a la parrilla y desarrollar una propuesta de rediseño que optimice el desempeño y bienestar laboral. La investigación se centró en dos áreas críticas: asado de pollo y estación de caja. Se empleó un diseño descriptivo y transversal mediante la aplicación del método RULA (*Rapid Upper Limb Assessment*) para la cuantificación de la carga postural. Como resultados se detectaron niveles de riesgo críticos asociados a posturas forzadas, movimientos repetitivos y estrés térmico. Se proponen mejoras técnicas enfocadas en el ajuste de estaciones de trabajo y protocolos de pausas activas, orientadas a mitigar la incidencia de TME y fortalecer la eficiencia operativa del proceso de producción.

Palabras clave: Sector Alimentos, RULA, Trastornos Musculoesqueléticos, Salud Ocupacional.

Relevancia para la ergonomía: La ergonomía es la interacción entre los seres humanos y otros elementos de un sistema. Este estudio aporta información que contribuye a la mejora de las condiciones de trabajo para empresa dedicada a la preparación de alimentos a la parrilla.

abstract: Globally and nationally, musculoskeletal disorders are the leading causes of work-related disability in the service sector. In Mexico, the Mexican Social Security Institute (IMSS) reports that conditions affecting the back and upper extremities result in a significant loss of workdays. In the state of Sinaloa, the growth of micro and small enterprises (MSEs) in the grilled food sector has revealed a lack of ergonomic infrastructure, characterized by long workdays and extreme thermal conditions. At the local level, this phenomenon results in low productivity and a progressive deterioration of workers' health in fast-food establishments. The objective is to evaluate ergonomic risk factors at workstations in a grilled food company and develop a redesign proposal that optimizes work performance and well-being. The research focused on two critical areas: chicken grilling and the checkout station. A descriptive, cross-sectional design was employed using the RULA (Rapid Upper Limb Assessment) method to quantify postural load. The findings revealed critical risk levels associated with awkward postures, repetitive movements, and thermal stress. Technical improvements are proposed that focus on adjusting workstations and implementing active break protocols, with the aim of reducing the incidence of musculoskeletal disorders and enhancing the operational efficiency of the production process.

Keywords: Ergonomics, Food Industry, RULA, Musculoskeletal Disorders, Occupational Health.

Relevance to ergonomics: Ergonomics is the interaction between humans and other elements of a system. This study provides information that contributes to improving working conditions for a company specializing in grilled food preparation.

1. INTRODUCTION

Ergonomics is a fundamental discipline in occupational safety and health, as it focuses on adapting working conditions to the physical and cognitive capabilities of workers in order to prevent injuries and improve efficiency in productive activities. Currently, ergonomic risks represent one of the main problems in various industrial sectors due to the presence of awkward postures, repetitive movements, and inadequate environmental conditions.

Globally, musculoskeletal disorders (MSDs) are a leading cause of work-related illness, affecting productivity and the quality of life of workers. In the industrial and service sectors, these ailments are directly related to activities involving physical exertion, repetitive tasks, and poor working conditions. The food industry, in particular, presents a high level of exposure to these risks, as workers perform repetitive tasks, handle materials, and remain in prolonged postures throughout the workday.

In Mexico, the food industry is of great economic importance, contributing approximately 5% to the Gross Domestic Product (GDP), which underscores the importance of analyzing working conditions within this sector. However, various

studies have demonstrated a high prevalence of musculoskeletal disorders in this type of industry, affecting up to 89% of workers, primarily in the back, neck, and upper extremities.

In this context, Pollos Boulevard, a company dedicated to grilling food preparation, has a production process that involves activities such as grilling chicken and customer service, both of which involve exposure to ergonomic risks. In the grilling area, workers perform tasks standing for extended periods, with repetitive movements and exposure to high temperatures; while at the cashier station, there are prolonged sedentary postures and continuous use of computer equipment. The main problem lies in the potential presence of ergonomic risk factors that can cause fatigue, discomfort, and musculoskeletal injuries in workers, directly impacting their performance, well-being, and productivity. Therefore, this study aims to conduct an ergonomic analysis of the workstations at Pollos Boulevard, with the goal of identifying existing risks and proposing improvements that will optimize working conditions and reduce the likelihood of injuries.

2. OBJECTIVE

Conduct an ergonomic analysis of the workstations at the company specializing in grilled food preparation by applying assessment methods, with the aim of identifying and analyzing postural, environmental, and occupational risk factors present in the production process, particularly in the chicken grilling and customer service areas.

3. METHODOLOGY

1. Conduct a diagnostic assessment of the company's production process through walkthroughs, identifying the characteristics of workers and workstations that negatively impact the health and safety of the operators. This is achieved by identifying STPS standards and ergonomic principles.

2. Identify the area with the highest incidence of risk in the company dedicated to preparing grilled food. Two critical stations were analyzed: the chicken grilling area and the cashier station, which presents the greatest risk to worker well-being. Evaluations are conducted to identify musculoskeletal injuries and cumulative trauma disorders using ergonomic assessment methods.

3. Design ergonomic and safety conditions in the quality control laboratory to ensure improved productivity. Realizar un diagnóstico del proceso productivo de la empresa mediante recorridos, identificando las características de los trabajadores y puestos de trabajo que perjudican la salud y seguridad del operario. Esto se logra mediante la identificación de las Normas STPS y los principios ergonómicos.

4. RESULTS

The results obtained from the ergonomic assessment at Pollos Boulevard reveal significant risks in the analyzed workstations, primarily in the chicken roasting area and the cashier station. Through direct observation, human-machine system analysis, and the development of a risk matrix, the roasting area was identified as having the highest risk levels (NR=9), associated with bent torso postures and exposure to high temperatures, which increases physical fatigue and heat stress. Medium-level risks related to burns and slips due to floor conditions were also detected. At the cashier station, the identified risks were of a medium level (NR=4–6), notably prolonged sedentary postures, neck strain due to incorrect monitor height, and repetitive hand and wrist movements, which generate static load and muscle fatigue.

The application of ergonomic assessment methods such as RULA and the pain and discomfort map confirmed the impact on body areas such as the neck, lower back, shoulders, and upper extremities, directly associated with the observed working conditions. Similarly, the evaluation of compliance with Mexican Official Standards revealed deficiencies in aspects such as thermal conditions, lighting, lack of technical studies, and absence of formal occupational safety and health programs. Taken together, these results demonstrate that the current conditions of the workstations require ergonomic intervention, as they negatively affect the health, comfort, and performance of workers, justifying the need to implement improvements in workstation design, environmental conditions, and work organization.



Figure 1. Chicken roasting station

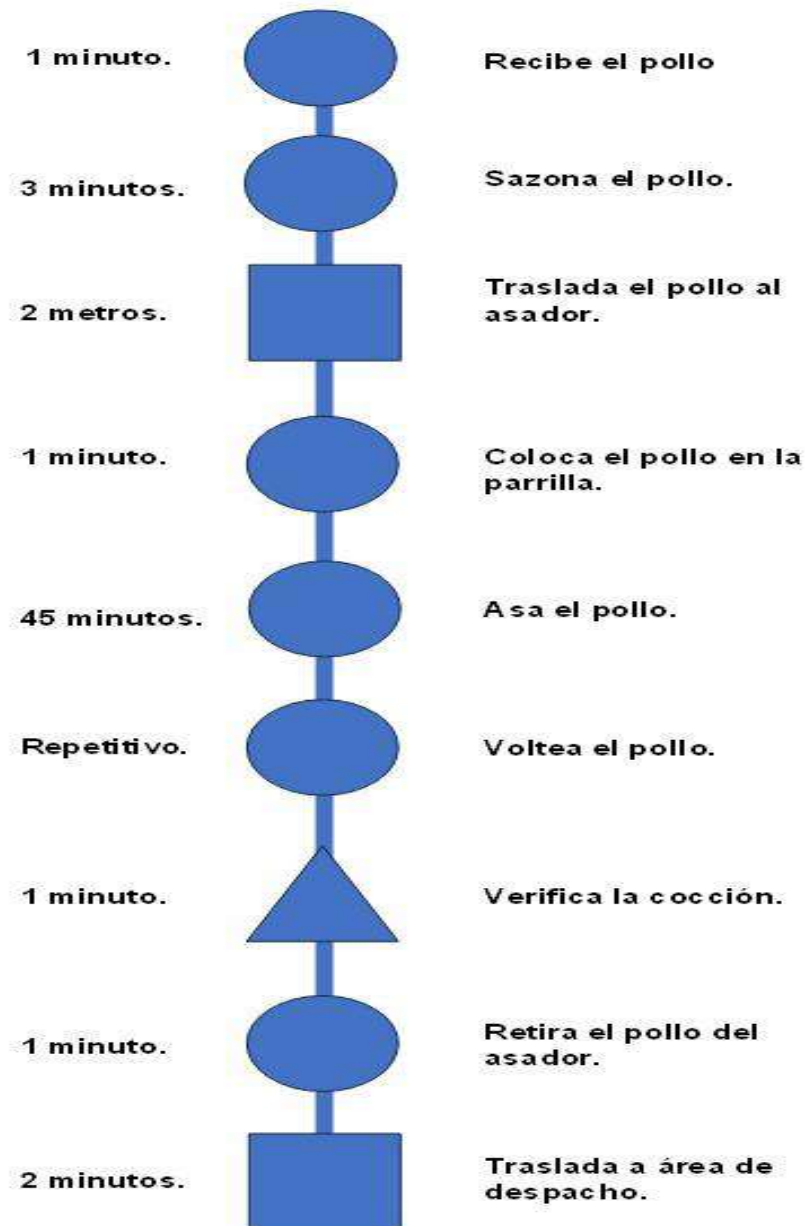
**DIAGRAMA DE FLUJO
ESTACION DE ASADO DE POLLOS**

Figure 2. Operation diagram of the chicken roasting station

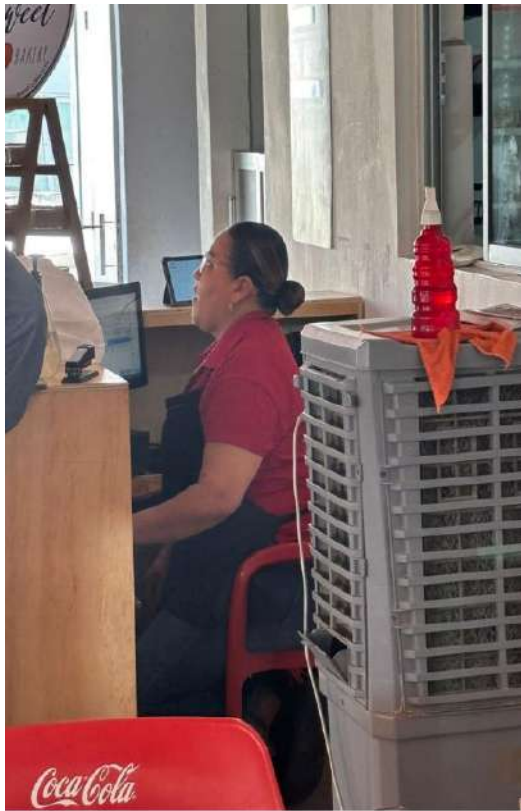


Figure 3. Payment Station

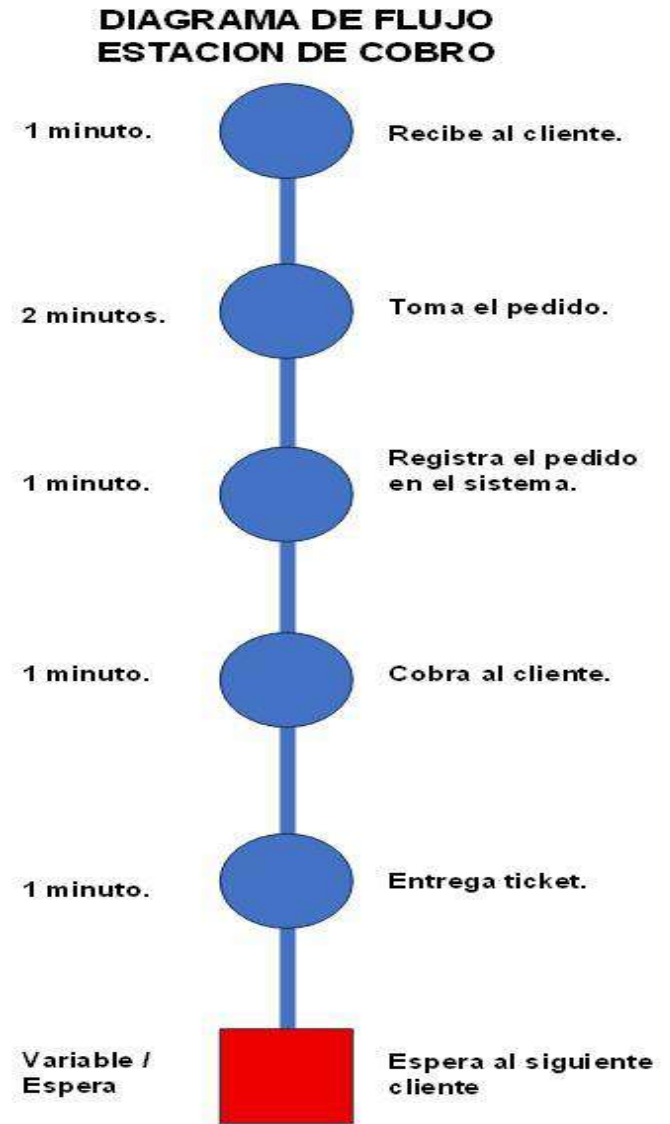


Figure 4. Flowchart collection Station

Table 1. Identification of Official Mexican Standards of the STPS.

Compliance with key safety and hygiene aspects, which increases exposure to occupational risks.			
Empresa: Pollos Boulevard			
Giro: Preparación de alimentos a la parrilla. (pollo asado)			
Date: 15/12/2025			
Norma	Si	No	Observation
NOM-015-STPS-2001, Condiciones térmicas elevadas o abatidas en los centros de trabajo	X		Workers are exposed to high temperatures due to the constant use of ovens, grills, and fire in the barbecue area. Insufficient measures such as adequate ventilation, recovery breaks, or staff rotation are lacking, which can lead to heat stress, dehydration, and fatigue.
NOM-025-STPS-2008, Condiciones de iluminación en los centros de trabajo		X	There is no formal measurement of lighting levels. Some areas rely on natural light or insufficient artificial lighting, which can lead to eye strain, errors in food preparation, and an increased risk of accidents.
NOM-011-STPS-2001, Condiciones de seguridad e higiene en centros de trabajo donde se genere ruido	X		Noise levels from exhaust fans, ventilation systems, and kitchen equipment are perceived as being within permissible limits; however, there is no formal monitoring or record-keeping. Hearing protection is not provided as a preventative measure.
NOM-035-STPS-2018, Factores de riesgo psicosocial en el trabajo		X	There is no formal system in place to identify and assess psychosocial risks. Staff may experience stress due to long working hours, high temperatures, and constant workload, without organizational measures in place for its prevention or management..
NOM-017-STPS-2008, Equipo de protección personal		X	Adequate personal protective equipment, such as thermal gloves, heat-resistant aprons, or non-slip footwear, is not provided. This increases the risk of burns, cuts, and falls in the work area.

Table 2. Ergonomic principles applied to workstation 1 y 2

Principles	Remarks
Principle 1: Neutral Posture Maintenance Principle (Physical Ergonomics)	In the laboratory station (RULA 7), this principle is violated due to material handling at ground level, forcing trunk flexion greater than 60°, which generates pain in the middle and lower back. In the control room (RULA 6), the furniture does not allow a 90-90-90 posture, resulting in prolonged static posture and discomfort in the upper, middle, and lower back.
Principle 2: Work Temporal Organization Principle (Organizational and Cognitive Ergonomics)	This principle is not met due to working shifts ranging from 10 to 17 hours without a fixed schedule. This condition prevents proper worker recovery and limits the implementation of active breaks, increasing fatigue associated with RULA 6 and RULA 7 risk levels.
Principle 3: Environmental Comfort and Safety Principles (Environmental Ergonomics)	Lack of noise control (NOM-011) leads to constant worker exposure. Additionally, absence of maintenance and personal protective equipment (NOM-024) increases vibration-related risks. Thermal comfort is also compromised due to lack of temperature monitoring and inadequate protective measures (NOM-015).
Principio 2: Use elbow height as a reference.	The height of the grill and work tables is not at the worker's elbow height, causing unnecessary strain on the arms and shoulders. It is recommended to adjust the working height to reduce fatigue and improve task efficiency.
Principio 3: Working within the comfort zone.	El asador realiza movimientos fuera de su alcance cómodo al manipular los pollos en parrillas amplias, lo que incrementa el esfuerzo físico. Es recomendable reorganizar el área para que los utensilios y productos estén dentro de un rango accesible.
Principio 4: Encontrar la posición correcta para cada tarea.	The grill cook has to make movements beyond their comfortable range of motion when handling chickens on large grills, which increases physical exertion. It is recommended to reorganize the area so that utensils and products are within easy reach.
Principio 5: Reduce repetitive movements	Activities such as turning chickens, cutting, and serving are constantly repeated throughout the workday, which can cause muscle fatigue and repetitive strain injuries. Implementing active breaks and job rotation is recommended.
Principio 6: Minimize fatigue	The combination of physical exertion, heat, and long working hours causes worker fatigue. Sometimes, the work is performed in high-temperature conditions without adequate rest periods.
Principio 7: Minimizar la presión directa.	El trabajador permanece de pie sobre superficies duras y puede utilizar calzado inadecuado, lo que genera presión en pies y piernas. Se recomienda el uso de tapetes antifatiga y calzado ergonómico.

The analysis of compliance with Mexican Official Standards revealed that Pollos Boulevard has significant deficiencies in occupational safety and health, particularly regarding thermal conditions, lighting, psychosocial factors, and the use of personal protective equipment. Although some standards, such as NOM-015-STPS-2001 and NOM-011-STPS-2001, are considered partially compliant, the absence of formal controls, monitoring, and documentation was identified, which limits effective risk prevention. Furthermore, non-compliance with standards such as NOM-025-STPS-2008, NOM-035-STPS-2018, and NOM-017-STPS-2008 reflects the lack of a structured occupational safety and health management system.

Taken together, these results demonstrate that the company needs to implement corrective actions aimed at regulatory compliance, such as improving environmental conditions, establishing risk prevention programs, and providing adequate protective equipment, in order to reduce exposure to hazards, prevent injuries, and ensure a safer and more efficient work environment.

4.1. Application of ergonomic evaluation methods in station 1 y 2.

Método R.U.L.A. Hoja de Campo

A. Análisis de brazo, antebrazo y muñeca

Paso 1: Localizar la posición del brazo

Paso 2: Localizar la posición del antebrazo

Paso 3: Localizar la posición de la muñeca

Paso 4: Giro de muñeca

Paso 5: Localizar puntaje postural en Tabla A

Utilizar valores de pasos 1, 2 y 3 para localizar puntaje postural en Tabla A

Paso 6: Añadir puntaje de uso muscular

Si la postura es principalmente estática (p.e. agarres superiores a 1 min.) o si suelte rápidamente la acción (4 veces/min. o más): +1

Paso 7: Añadir puntaje de la fuerza / carga

Si el peso o fuerza < 2 Kg. intermitente: +1
Si el peso o fuerza < 2 Kg. intermitente: +1
Si el peso o fuerza < 2 Kg. intermitente: +1
Si el peso o fuerza < 2 Kg. intermitente: +1

Paso 8: Localizar fila en Tabla C

Ingresar a Tabla C con la suma de los pasos 6, 7 y 8

B. Análisis de cuello, tronco y piernas

Paso 9: Localizar la posición del cuello

Paso 10: Localizar la posición del tronco

Paso 11: Localizar la posición de las piernas

Paso 12: Localizar puntaje postural en Tabla B

Utilizar valores de pasos 9, 10 y 11 para localizar puntaje postural en Tabla B

Paso 13: Añadir puntaje de uso muscular

Si la postura es principalmente estática (p.e. agarres superiores a 1 min.) o si suelte rápidamente la acción (4 veces/min. o más): +1

Paso 14: Añadir puntaje de la fuerza / carga

Si el peso o fuerza < 2 Kg. intermitente: +1
Si el peso o fuerza < 2 Kg. intermitente: +1
Si el peso o fuerza < 2 Kg. intermitente: +1
Si el peso o fuerza < 2 Kg. intermitente: +1

Paso 15: Localizar columna en Tabla C

Ingresar a Tabla C con la suma de los pasos 12, 13 y 14

Tabla A: Muñeca

	1	2	3	4
1	1	2	3	4
2	2	3	4	5
3	3	4	5	6
4	4	5	6	7
5	5	6	7	8
6	6	7	8	9
7	7	8	9	10
8	8	9	10	11
9	9	10	11	12
10	10	11	12	13

Tabla B: Cuello, Tronco y Piernas

	1	2	3	4	5	6	7	8
1	1	2	3	4	5	6	7	8
2	2	3	4	5	6	7	8	9
3	3	4	5	6	7	8	9	10
4	4	5	6	7	8	9	10	11
5	5	6	7	8	9	10	11	12
6	6	7	8	9	10	11	12	13
7	7	8	9	10	11	12	13	14
8	8	9	10	11	12	13	14	15
9	9	10	11	12	13	14	15	16
10	10	11	12	13	14	15	16	17

Tabla C: Fila y Columna

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
3	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
4	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20				
6	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20					
7	7	8	9	10	11	12	13	14	15	16	17	18	19	20						
8	8	9	10	11	12	13	14	15	16	17	18	19	20							
9	9	10	11	12	13	14	15	16	17	18	19	20								
10	10	11	12	13	14	15	16	17	18	19	20									
11	11	12	13	14	15	16	17	18	19	20										
12	12	13	14	15	16	17	18	19	20											
13	13	14	15	16	17	18	19	20												
14	14	15	16	17	18	19	20													
15	15	16	17	18	19	20														
16	16	17	18	19	20															
17	17	18	19	20																
18	18	19	20																	
19	19	20																		
20	20																			

Empresa: Pollos boulevard Fecha: 10/Diciembre/25

Puesto / Sección: Estación asado de pollos

Referencias: Lessly Leyva Firma: Lessly V.

Puntuación final: 5

Puntuación final: 1 ó 2: Aceptable; 3 ó 4: Ampliar el estudio; 5 ó 6: Ampliar el estudio y modificar pronto; 7: estudiar y modificar inmediatamente

Figure 1 Application of the RULA Method in workstation 1

Método R.U.L.A. Hoja de Campo

A. Análisis de brazo, antebrazo y muñeca

Paso 1: Localizar la posición del brazo

Paso 2: Localizar la posición del antebrazo

Paso 3: Localizar la posición de la muñeca

Paso 4: Giro de muñeca

Paso 5: Localizar la puntuación postural en Tabla A

Paso 6: Añadir puntuación utilización muscular

Paso 7: Añadir puntuación de la fuerza / carga

Paso 8: Localizar fila en Tabla C

B. Análisis de cuello, tronco y piernas

Paso 9: Localizar la posición del cuello

Paso 10: Localizar la posición del tronco

Paso 11: Localizar la posición de las piernas

Paso 12: Localizar puntuación postural en Tabla B

Paso 13: Añadir puntuación utilización muscular

Paso 14: Añadir puntuación de la fuerza / carga

Paso 15: Localizar columna en Tabla C

Referencias: Lessly Leyva

Observador: Lessly V.

Puntuación Final: 1 ó 2: Aceptable; 3 ó 4: Ampliar el estudio; 5 ó 6: Ampliar el estudio y modificar pronto; 7: estudiar y modificar inmediatamente

Figure 2 Application of the RULA Method in workstation 2

4.2. Design of ergonomic conditions in the work station 1 y 2.

Based on the findings derived from the ergonomic analysis—supported by the RULA method, the risk identification matrix, and the regulatory framework of the Mexican Official Standards (NOM) structural interventions were designed to optimize the workstation in the grilling area. First, the work surface was adjusted using the operator's popliteal or elbow height as a reference point; this measure aims to mitigate trunk flexion and reduce biomechanical stress in the lumbar region. Additionally, the integration of anti-fatigue footrests is proposed to alleviate musculoskeletal exhaustion from prolonged standing. Finally, to optimize load handling, ergonomically designed tools were selected, such as tongs with non-slip grips and thermal insulation, designed to minimize mechanical stress on the hand-wrist complex.

Regarding environmental conditions, improvements to ventilation through exhaust fans or airflow systems are proposed to reduce exposure to high temperatures and prevent heat stress. Additionally, implementing active breaks and job rotation is recommended to decrease physical workload and prevent accumulated fatigue in workers.

Finally, the implementation of appropriate personal protective equipment, such as thermal gloves, heat-resistant aprons, and non-slip footwear, is proposed to reduce the risk of accidents and injuries. These improvements aim to optimize

working conditions, prevent musculoskeletal disorders, and increase operator productivity.

5. CONCLUSIONS

The ergonomic analysis conducted at Pollos Boulevard identified several risk factors in the workstations, primarily in the chicken roasting area and the cashier station, which directly affect the health, safety, and performance of the workers. Problems were detected related to awkward postures, repetitive movements, static load, and inadequate environmental conditions, such as exposure to high temperatures and deficiencies in lighting and ventilation.

The application of ergonomic assessment methods such as RULA and the pain and discomfort map revealed that workers primarily experience discomfort in the neck, back, shoulders, and upper extremities, highlighting the need for interventions in the design of the workstations. Furthermore, the analysis of the Official Mexican Standards showed low compliance in key aspects of safety and hygiene, which increases exposure to occupational hazards.

Based on these results, ergonomic improvements were proposed, focusing on adjusting workstation heights, implementing appropriate tools, using personal protective equipment, improving environmental conditions, and reorganizing work processes. These actions help reduce fatigue, prevent musculoskeletal injuries, and improve worker well-being.

In conclusion, implementing proper ergonomic design not only contributes to worker safety and health but also positively impacts productivity, efficiency, and process quality, generating benefits for both the worker and the company.

Compliance with key safety and hygiene aspects, which increases exposure to occupational risks.

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DESIGN OF A TELESCOPIC HANDLE FOR REDUCING UPPER EXTREMITY INJURIES

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Resumen La presente investigación muestra el diseño de un mango telescópico retráctil para la disminución de lesiones de extremidades superiores, con la finalidad de brindar una alternativa a los usuarios, disminuyendo las lesiones de sus muñecas al hacer uso de la herramienta de manera repetitiva.

Los trastornos musculoesqueléticos del miembro superior constituyen una de las principales fuentes de incapacidad laboral a escala global. La Organización Mundial de la Salud indica que “los trastornos musculoesqueléticos son la causa predominante de discapacidad en el mundo” (OMS, 2021), afectando especialmente a personas trabajadoras expuestas a movimientos repetitivos y posiciones forzadas de la muñeca. Diversas investigaciones han evidenciado que la combinación de fuerza elevada, repetición constante y desviaciones angulares aumenta la probabilidad de desarrollar síndrome del túnel carpiano y tendinopatías (Armstrong et al., 2008; Punnett & Wegman, 2004).

El presente trabajo plantea el diseño y la validación de un mango telescópico de carácter ergonómico, orientado a conservar la muñeca en posición neutra ($\pm 15^\circ$), disminuir la fuerza de prensión necesaria y ajustarse a distintos percentiles antropométricos mediante un mecanismo de regulación longitudinal (60–120 cm). La propuesta incorpora una inclinación ergonómica de 15° , recubrimiento antideslizante y un material liviano (aluminio anodizado), con la finalidad de reducir la carga biomecánica transmitida a la articulación radiocarpiana.

La metodología considera un estudio cuasi experimental con diseño intra sujeto, en el que se comparará un mango tradicional frente al prototipo telescópico. Se analizarán variables como la desviación angular (medida con goniómetro digital), la actividad muscular (evaluada mediante electromiografía superficial), el riesgo postural a través del método RULA y la percepción subjetiva del esfuerzo utilizando la escala de Borg. Se proyecta una disminución $\geq 25\%$ en la desviación angular y $\geq 20\%$ en la activación electromiográfica, además de una menor sensación de fatiga.

La propuesta constituye una intervención ergonómica de tipo ingenieril, coherente con las directrices internacionales en materia de prevención de riesgos

laborales, y muestra potencial de aplicación y transferencia tecnológica en ámbitos industriales, agrícolas y de servicios.

Palabras clave: ergonomía, trastornos musculoesqueléticos, mango telescópico.

Abstract This research presents the design of a retractable telescopic handle to reduce upper limb injuries, aiming to provide users with an alternative and decrease wrist injuries caused by repetitive tool use.

Musculoskeletal disorders of the upper limb are a leading cause of work disability worldwide. The World Health Organization states that “musculoskeletal disorders are the predominant cause of disability globally” (WHO, 2021), particularly affecting workers exposed to repetitive movements and awkward wrist positions. Various studies have shown that the combination of high force, constant repetition, and angular deviations increases the likelihood of developing carpal tunnel syndrome and tendinopathies (Armstrong et al., 2008; Punnett & Wegman, 2004).

This work presents the design and validation of an ergonomic telescopic handle, intended to maintain the wrist in a neutral position ($\pm 15^\circ$), reduce the required gripping force, and adjust to different anthropometric percentiles through a longitudinal adjustment mechanism (60–120 cm). The design incorporates a 15° ergonomic tilt, a non-slip coating, and a lightweight material (anodized aluminum) to reduce the biomechanical load transmitted to the radiocarpal joint.

The methodology employs a quasi-experimental, within-subjects design, comparing a traditional handle against the telescopic prototype. Variables such as angular deviation (measured with a digital goniometer), muscle activity (evaluated using surface electromyography), postural risk (using the RULA method), and subjective perception of effort (using the Borg scale) will be analyzed. A reduction of $\geq 25\%$ in angular deviation and $\geq 20\%$ in electromyographic activation is projected, along with a reduced perception of fatigue.

The proposal constitutes an ergonomic engineering intervention, consistent with international guidelines on occupational risk prevention, and demonstrates potential for application and technology transfer in industrial, agricultural, and service sectors.

Keywords: ergonomics, musculoskeletal disorders, telescopic handle.

Relevance to Ergonomics: After the Keyword, write the importance of this article for ergonomics and why it is important its publication

1. INTRODUCTION

In the productive context, physical ergonomics acquires special importance, as it examines elements such as body postures, object handling, repetitive gestures, and force exertion. These conditions are directly related to the development of musculoskeletal disorders (MSDs), particularly in the upper extremities (Feletto et al., 2004).

The ergonomic design of hand tools is based on biomechanical principles aimed at:

- Maintaining the wrist in a neutral alignment
- Reducing excessive grip force
- Avoiding unnecessary repetitive movements
- Minimizing pressure exerted on the palm of the hand

Numerous studies have shown that inadequate tool design increases muscular overload and raises the likelihood of injuries to the hand, wrist, and forearm (Canada Centre for Occupational Health and Safety [CCOHS], 2020).

Anthropometry is the discipline that analyzes the measurements and proportions of the human body and represents the numerical foundation of ergonomic design (Pheasant, 2003). In the case of hand tools, anthropometric parameters of the hand such as palm length, width, grip circumference, and grip strength—are essential to determine the appropriate handle diameter and length.

Design based on population percentiles (commonly from the 5th to the 95th) allows tools to be usable by the majority of people (Pheasant, 2003). When the handle diameter does not match the dimensional characteristics of the user's hand, muscle activity and fatigue sensation increase (Arciniega-Rocha et al., 2022).

Likewise, scientific evidence indicates that handles that are too small increase concentrated pressure on soft tissues, while excessively thick handles limit the ability to apply effective force (Feletto et al., 2004).

Hand and wrist injuries are the leading cause of disability due to workplace accidents in Mexico, according to data from the Mexican Social Security Institute (IMSS) and the Ministry of Health of Mexico City (CDMX). These injuries account for approximately 26% to 36% of all occupational accidents, with their main causes being repetitive movements and improper use of hand tools.

Hand tools and wrench design, Smith & Jones (2015) state that “hand tool design combines principles of mechanics of materials, ergonomics, and manufacturing.” On the other hand, Hand Tool Engineering (2012) explains that Stilson wrenches (pipe wrenches) use serrated jaws to grip iron pipes or other materials, and their classic design is based on a rigid body with a fixed jaw and a movable jaw adjusted by a spindle or worm screw.

In this type of tool, it is necessary to consider lever principles and force transmission. The former explains why a longer handle reduces the force required to generate the same moment (Beer, Johnston & Mazurek, 2016). However, in these tasks, the load transmitted to the tool and to the jaw-body joint increases, so the design must consider flexing and fatigue stresses (Shigley & Mischke, 2001).

Ergonomics and safety in hand tools have a significant influence, as tools must adapt to users. User anthropometry reduces the risk of musculoskeletal injuries by considering user dimensions during the design process. For tool-use tasks, factors such as handle length, grip surface, usage angle, and weight influence posture and effort (Dul & Weerdmeester, 2008). Secure locking mechanisms and accessible controls minimize accidents due to collapse.

Telescopic handles with discrete positions typically use locking pins, threaded collars, or detent systems (notch + ball) to fix the length (Norton, 2014). The selection

of the mechanism must balance ease of use, robustness, and resistance to wear from dirt and corrosion.

For impact and torsion tools, alloy steels with heat treatment (quenching and tempering) are recommended for the jaw and main body; the handle can be hollow carbon or alloy steel with anti-corrosion coating (Callister, 2018). Typical processes include forging, machining, and heat treatment for main components, and stamping for auxiliary parts.

Ergonomic design is grounded in the discipline of ergonomics, conceived as the science that analyzes the relationship between people and system components, with the aim of promoting human well-being and optimizing overall system performance (International Ergonomics Association [IEA], n.d.). From this perspective, ergonomic design seeks to adapt products, tools, spaces, and activities to users' abilities, restrictions and particularities of the users.

Ergonomics integrates knowledge from physiology, biomechanics, psychology, and anthropometry to propose solutions that reduce occupational risks and increase productivity and comfort (Dul & Weerdmeester, 2008). In the industrial field, ergonomic design primarily aims to prevent musculoskeletal disorders (MSDs), physical fatigue, and human errors associated with poor environmental or equipment configurations (Bridger, 2018).

Musculoskeletal disorders (TME) of the upper limb constitute one of the main occupational health problems worldwide. The World Health Organization states that: "musculoskeletal disorders are the leading cause of disability worldwide" (OMS, 2021, p. 1).

These conditions particularly affect workers exposed to repetitive movements, awkward postures, and sustained manual force application. In the workplace, the International Labour Organization warns that: "awkward postures, repetitive movements, and load handling are determining factors in the occurrence of occupational diseases" (OIT, 2019, p. 21).

From a biomechanical perspective, the wrist is a highly vulnerable joint due to its function of transmitting forces between the hand and forearm. According to Neumann (2017), "the wrist is designed to balance mobility and stability while transmitting forces generated by the forearm muscles" (p. 412).

When the wrist is maintained in radial or ulnar deviation, flexion, or extension outside the neutral posture, intracarpal pressure increases along with the risk of median nerve compression. In this regard, Rempel, Keir, and Bach (2008) demonstrated that: "carpal tunnel pressure increases significantly with wrist flexion and high grip force" (p. 1272).

Epidemiological evidence supports the relationship between force, repetition, and awkward posture in the development of TME. Armstrong et al. (2008) note that: "high repetition, forceful exertions, and extreme wrist postures are consistently associated with increased risk of carpal tunnel syndrome" (p. 230).

Similarly, Punnett and Wegman (2004) conclude that: "the strongest evidence for work-related musculoskeletal disorders is found for combinations of force, repetition, and awkward posture" (p. 15).

In this context, ergonomics proposes engineering interventions aimed at adapting tools to the user. Dul and Weerdmeester (2012) state that: "ergonomics

aims to design products, tasks, and environments that fit human capabilities and limitations” (p. 6).

Among the most effective strategies is design adjustability, since, as Pheasant and Haslegrave (2006) indicate: “adaptability is one of the most effective strategies for accommodating human variability” (p. 34).

Based on this evidence, the present project proposes the design of an ergonomic telescopic handle that allows the wrist to remain in a neutral position, reduces the required grip force, and adapts to different anthropometric percentiles through a longitudinal adjustment system. It is proposed that an engineering type intervention can reduce cumulative biomechanical load and contribute to the prevention of occupational injuries in industrial, agricultural, and service sectors.

2. METODOLOGY

A descriptive study was conducted to determine the main effects associated with performing repetitive tasks using a Stilson wrench. The study population consisted of plumbers. Additionally, an evaluative assessment was carried out to determine the level of risk to which individuals engaged in this occupation are exposed.

A posture analysis was performed using the RULA method to determine the degree of exposure risk. Subsequently, specialized software was used for the design of the retractable extension.

In this research, a design was developed that helps reduce the effort required in torque-related activities, specifically when using Stilson wrenches. This is because the design is based on the law of moments, better known as the lever principle, which describes the relationship between the applied force and the distance to the point of support. This relationship is determined by the moment or torque, represented as:

$$\tau = F \cdot r \cdot \sin(\theta)$$

F: Applied force in Newtons (N).

r: Magnitude of the lever arm (distance from the axis to the point of application)

θ : Angle formed between the force vector and the lever arm.

3. RESULTS

Next, results of RULA analysis are presented

Section A. Superior member evaluation

Arm position	Score
0°–20° flexion/extension	1
20°–45° flexion	2
45°–90° flexion	3
>90° flexion	4

Extension >20°	+1
Abduction	+1
Elevated shoulder	+1

Table 1. Arm position

Forearm position analysis

Elbow angle	Score
60°–100°	1
<60° o >100°	2

Table 2. Forearm analysis

Wrist evaluation

Wrist position	Score
0°–15°	1
>15° flex/ext	2
Radial deviation/ulnar	+1

Table 3. Wrist evaluation.

Wrist turn

Position	Score
Posición neutra	1
Giro extremo	2

Table 4. Wrist turn.

Muscular and strength adjustments

Condition	Additional Score
Hold posture >1 min	+1
Repetitive movement	+1
Measured strength	+1
High strength (>10 kg manual effort)	+2

Table 5. Strength application analysis.

Section B. Neck, Trunk and legs

Neck

Position	Score
0°–10°	1
10°–20°	2
>20°	3
Extension	4

Turn or lateral incline	+1

Table 6. Postural neck analysis.

Trunk.

Position	Score
0°–5°	1
5°–20°	2
20°–60°	3
>60°	4
Turn or lateral incline	+1

Table 7. Trunk evaluation

Legs

Condition	Score
Supported and balanced	1
Unstable , unbalanced	2

Table 8. Leg position analysis.

Next, the calculation of the final score is presented:

- Score A is obtained (upper limb)
- Score B is obtained (neck–trunk–legs)
- Both scores are cross-referenced in the final RULA table
- Final value obtained: 7

The table for interpreting the result is presented below.

Final score	Riesgo level	Action
1–2	Low	Not required
3–4	Moderate	Check changes
5–6	High	Changes soon
7	Very high	Immediate change

Table 9. Results interpretation.

At the conclusion of the evaluation, a score of 7 was obtained; therefore, immediate changes are recommended.

The proposed design is presented below, with the purpose of reducing the effort exerted on the wrist.

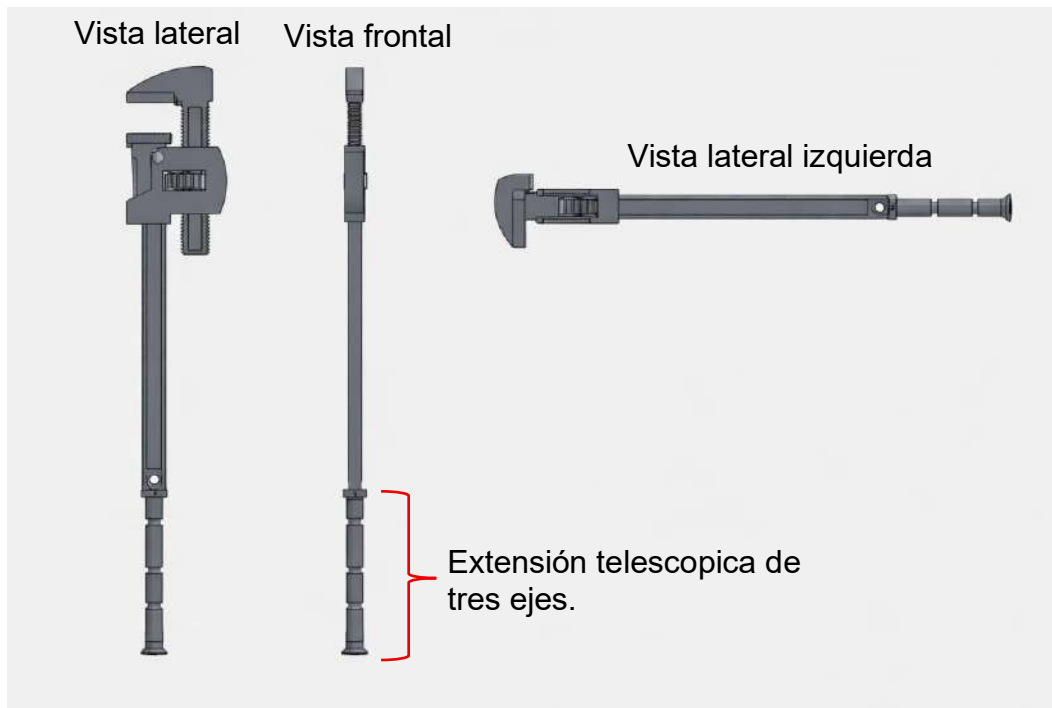


Figure1. Look at proposed design.

The figure shows the different views of the three-axis telescopic extension. Due to its dimensions, it is intended to reduce the stress applied to the radiocarpal joint, better known as the wrist.

4. CONCLUSIONS

By applying the RULA analysis, the need to design a retractable handle extension was identified in order to minimize the effort required when performing plumbing tasks, specifically when using Stilson wrenches. This design will be capable of reducing the risk of wrist injuries when carrying out repetitive rotational tasks that require force.

Ergonomic Recommendations

- Use of a Stilson wrench with an extended handle (reduces required force)
- Use of two wrenches (counterforce technique)
- Improvement of working height
- Use of knee pads when working under sinks
- Active breaks
- Use of tools with non-slip handles

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ERGONOMIC DIAGNOSTIC OF POSTURE RISK ON AGRICULTURAL PRODUCERS IN AN ARTISANAL PROCESS.

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Resumen: El proyecto propone una solución enfocada en pequeños productores mediante el diseño y la construcción de un sistema ergonómico, portátil, fácil de armar y usar.

Este sistema fue diseñado considerando las dimensiones antropométricas de los pequeños productores del noreste de México, con el objetivo de reducir las lesiones musculoesqueléticas durante sus actividades laborales, que consisten en el proceso de extracción de semillas.

Según el Programa Nacional de Semillas 2020-2024, un programa especial derivado del Plan Nacional de Desarrollo 2019-2024 (Diario Oficial de la Federación, 2020). En México, según estadísticas publicadas por el Servicio de Información Agroalimentaria y Pesquera (SIAP), se sembraron 21.2 millones de hectáreas en el año agrícola 2018, caracterizado por la gran diversidad de sus regiones productoras. De los 21.2 millones de hectáreas sembradas, el 79% se concentra en nueve cultivos: maíz, pastos, sorgo, frijol, caña de azúcar, café, avena, trigo y arroz. El maíz y los frijoles se cultivan en casi todo el territorio y son los cultivos con mayor diversidad (SIAP, 2018).

Este proyecto impacta los Programas Estratégicos Nacionales (PRONACES), específicamente los relacionados con la Seguridad Humana, la Salud y los Contaminantes. Además, se enfoca en abordar los Objetivos de Desarrollo Sostenible (ODS) establecidos por la ONU en la Agenda 2030, específicamente los objetivos de Fin de la Pobreza, Salud y Bienestar, Trabajo Decente y Crecimiento Económico, y Producción y Consumo Responsables.

Palabras clave: extracción, semillas, lesiones musculoesqueléticas

Abstract: The project proposes a solution focused on small-scale producers through the design and construction of an ergonomic, portable, easy-to-assemble and use system.

This system was designed considering the anthropometric dimensions of small-scale producers in northeastern Mexico, with the goal of reducing musculoskeletal injuries during their work activities, which consist of the seed extraction process.

According to the National Seed Program 2020-2024, a special program derived from the National Development Plan 2019-2024 (Official Gazette of the Federation, 2020).

In Mexico, according to statistics published by the Agri-Food and Fisheries Information Service (SIAP), 21.2 million hectares were planted in the 2018 agricultural year, characterized by the great diversity of its producing regions. Of the 21.2 million hectares planted, 79% of the area is concentrated in nine crops: corn, pastureland, sorghum, beans, sugarcane, coffee, oats, wheat, and paddy rice. Corn and beans are planted across almost the entire territory and are the crops with the greatest diversity (SIAP, 2018).

This project impacts the National Strategic Programs (PRONACES), specifically those related to Human Security, Health, and Pollutants.

Furthermore, it focuses on addressing the Sustainable Development Goals (SDGs) issued by the UN in the 2030 Agenda, specifically the goals of No Poverty, Good Health and Well-being, Decent Work and Economic Growth, and Responsible Consumption and Production.

Keywords: extraction, seeds, musculoskeletal injuries.

1. INTRODUCTION

The artisanal process for the extraction of bean seeds from the seedcases is a task that entails making a series of physical efforts, to realize the extraction of the legume from the shell. There exist systems that let an automated extraction of this process, however, the cost its acquisition entails are not feasible for the small producer or even due to the lack of electric energy they can't make use of them, resulting in the need to use the traditional method.

At the present, the small producers of seeds realize their extraction process using traditional methods, which generate musculoskeletal injuries over time at the moment of performing their job.

Traditionally, small scale agriculture has been related to the concept of farmers, who are noted as the rural producer in a traditional culture. Macias (2013)

The illness and trauma that affect the musculoskeletal system and generate handicaps are considered in present times as a grave public sector problem, due their magnitude, impact, and transcendence (Ibarra, 2013).

In actuality, it's not possible to think of a modern and cheap production without the intervention of mechanical equipment to minimize or facilitate the rural task. Even more, the mechanization of them help to satisfy the oppressed people hunger and frees them from the huge efforts of fieldwork. Negrete (2011).

For Perea (2015), competitiveness must be understood as the capacity that an organization has, public or private, profit oriented or not, to obtain and maintain competitive advantage that let it reach, hold and improve a specific position in the socioeconomical environment.

For the purpose of reaching a competitive advantage, an organization must develop value creation functions at a smaller cost than their rivals or develop them in a way that generates differentiation and a superior price. This will help it achieve superior levels of efficiency, quality, innovation and client satisfaction capacity. (Hill, 2009).

Due to the advancements of technologies and the concern to improve working conditions of workers, there has been development of Methods of Observational Evaluations (MEO), to evaluate the biomechanical risk (ERB) associated to musculoskeletal disorders (DME). Angulo et al. (2020). For Yissi (2007) however, this processes of aperture and globalization have an uneven impact in diverse territories and segments of the population, often provoking or accentuating preexisting territorial and societal inequities.

Seeds are the fundamental supplies on all agricultural chains. The market price of seeds in Mexico is estimated in 1,000 million of dollars annually. Today there exist more than 600 business of social and commercial kind in the Certified seed production Program. The seeds on certified category required for the agricultural surface of the country is approximately 600 thousand tons each year. (SIAP, 2018).

The present study is based on an analysis of the evaluation method REBA, this method divides the body in two body group segments, being group A correspondent to trunk, neck and legs, and group B, formed by superior members (arms, forearms and wrist). For each one of this body segments we will get a point value, and with it the results of a series of tables, besides the application of their corresponding factors of correction and a final score of the method for each evaluated posture. At the present a great number of studies endorse the obtained results of the REBA method, consolidating it as one of the most spread and used tools in the analysis of postural load.

For this motive this methodology was selected, because it gives us concrete results with a high grade of veracity, also, applying this methodology will let us evaluate the most important tasks in the cultivation of beans, showing us if it feasible to make a corrective action or not to prevent musculoskeletal afflictions on workers.

2. METHODOLOGY

An investigation was made in the data collecting field, developing an assessing kind investigation, due to the way the information gathering was transversal, derived of missing a control of variables, this was a not experimental investigation.

Therefore, an evaluation of ergonomic postures through REBA analysis, of the principal activities of the process of bean cultivation that were evaluated using this methodology, the following ones were the most of note:

- Recollection.
- Storing.
- Loading and transporting.
- Pounding.

Next, the REBA methodology of evaluation is presented:

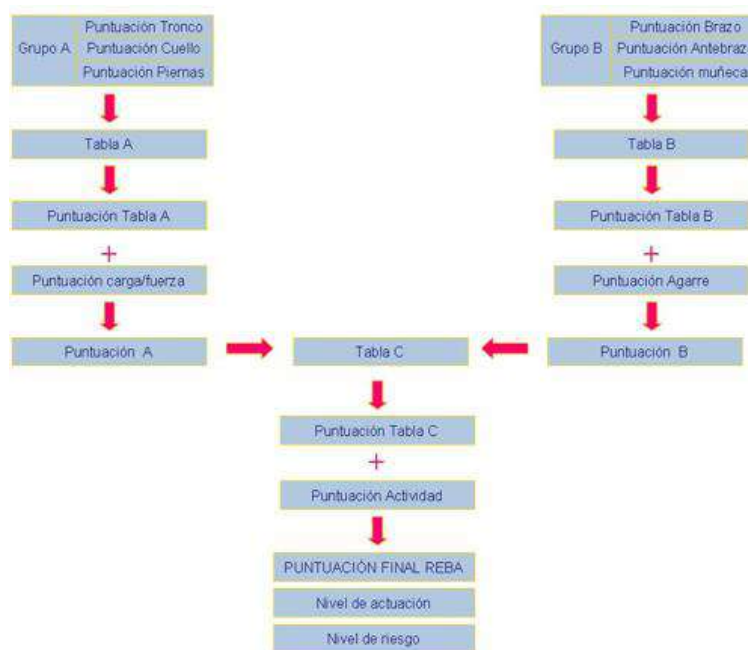


Figure 1. Methodology of REBA method of evaluation

3. RESULTS

This project was chosen among a series of problems identified that agricultural producers confront in the northeast region of Mexico.

The agricultural producers in the Tamaulipas and north of Veracruz regions present these deficiencies on their performance of their labors:

- Technological deficiencies for the harvesting labor.
- Shortage of economic resources for the acquisition of adequate technology.
- Rural producers in these zones are not organized, so the rental of machinery in an individual way would generate high costs.
- The topography of the terrain is irregular, so it difficults the labors with machinery.
- The process of obtention of crops is very costly when doing them manually.
- Way too much time is invested in the obtention of the product, especially beans.
- Production of seeds in the specific case of beans is of small competitiveness and significance.
- Spaces have to be adequated, like Tlapextle (Nahuatl denomination that means place for stick pounding) for the obtention of beans, so it causes loses on the pounding due the waste generated.

Analized porsture for work: seeking and selection of the seedcase of the bean ready to be collected

Up next, the results of the REBA analysis are presented.

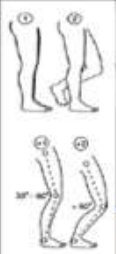
Data:

- Flexion on neck above 20°.
- Legs on bilateral support and flexed between 30° and 60°.
- Trunk flexed over 60°.
- The strength load is none, so, less than a kg.
- Forearm extended over 100°.
- The movement of the wrist is between 0° and 15° of flexion/extension, without torsion produced.
- Arm extension over 90°.
- Grip is considered irregular.
- It must be taken in account that significant changes of posture in the recollection of beans can hardly be present.

CUELLO

Movimiento	Puntuación	Corrección		2
0°-20° flexión	1	Añadir + 1 si hay torsión o inclinación lateral		
>20° flexión o en extensión	2			

PIERNAS

Movimiento	Puntuación	Corrección		2
Soporte bilateral, andando o sentado	1	Añadir + 1 si hay flexión de rodillas entre 30° y 60°		
Soporte unilateral, soporte ligero o postura inestable	2	Añadir + 2 si las rodillas están flexionadas + de 60° (salvo postura sedente)		

TRONCO

Movimiento	Puntuación	Corrección
Erguido	1	Añadir + 1 si hay torsión o inclinación lateral
0°-20° flexión 0°-20° extensión	2	
20°-60° flexión >20° extensión	3	
> 60° flexión	4	



4

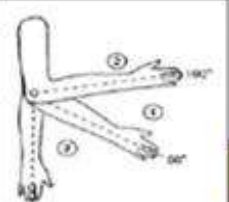
CARGA / FUERZA

0	1	2	+ 1	0
< 5 Kg.	5 a 10 Kg.	> 10 Kg.	Instauración rápida o brusca	

Figure 2. Posture 1: Group A evaluation.

The point section of the neck scores a value of 2 as it presents a flexion above 20°, legs a value of 2 because they are supported bilaterally and flexed between 30° and 60°, trunk presents a value of 4 because a flexion above 60°, finally, the user doesn't present a load or applied force, so that section has a value of 0.

ANTEBRAZOS

Movimiento	Puntuación	
60°-100° flexión	1	
flexión < 60° o > 100°	2	2

MUÑECAS

Movimiento	Puntuación	Corrección	
0°-15° flexión/ extensión	1	Añadir + 1 si hay torsión o desviación lateral	
>15° flexión/ extensión	2		

BRAZOS

Posición	Puntuación	Corrección
0°-20° flexión/ extensión	1	Añadir: + 1 si hay abducción o rotación.
>20° extensión	2	+ 1 si hay elevación del hombro.
flexión 20°-45°	2	-1 si hay apoyo o postura a favor de la gravedad.
flexión 45°- 90°	3	
>90° flexión	4	

4

AGARRE

0 - Bueno	1-Regular	2-Malo	3-Inaceptable	1
Buen agarre y fuerza de agarre	Agarre aceptable	Agarre posible pero no aceptable	Incómodo, sin agarre manual Inaceptable usando otras partes del cuerpo	

Figure 3. Posture 1: Grupo B evaluation

The score section of forearms gets a value of 2 because they are extended more than 100°, wrists a value of 1 due a flexion range between 0° and 15°, arms score a value of 4 because an extension above 90°, grip is considered regular and gets a score of 1.

Grupo A: Análisis de cuello, piernas y tronco

PUNTUACIÓN CUELLO ⁽¹⁻³⁾ :	2
PUNTUACIÓN PIERNAS ⁽¹⁻⁴⁾ :	2
PUNTUACIÓN TRONCO ⁽¹⁻⁵⁾ :	4
PUNTUACIÓN CARGA/FUERZA ⁽⁰⁻³⁾ :	0

Grupo B: Análisis de brazos, antebrazos y muñecas

PUNTUACIÓN ANTEBRAZOS ⁽¹⁻²⁾ :	2
PUNTUACIÓN MUÑECAS ⁽¹⁻³⁾ :	1
PUNTUACIÓN BRAZOS ⁽¹⁻⁶⁾ :	4
PUNTUACIÓN AGARRE ⁽⁰⁻³⁾ :	1

Figure 4. Posture 1: Data summary

The result of the addition of values of group A is 8, group B coincides with that value, presenting a total of 8. Next is a summary of posture evaluation.

NIVELES DE RIESGO Y ACCIÓN:	
Puntuación final REBA ⁽¹⁻¹⁵⁾	8
Nivel de acción ⁽⁰⁻⁴⁾	3
Nivel de riesgo	Alto
Actuación	Es necesaria la actuación cuanto antes

Figure 5. Posture 1: Risk levels and action

As it can be seen, the bean collection activity presents a notoriously high risk, if it keeps being done this way, it could present repercussions after an extended amount of work time. Corrective measures are necessary as soon as possible to prevent any musculoskeletal afflictions.

Analized porsture for work: storage of shell/bean seeds.

Data:

- Flexion on neck above 20°.
- Legs on bilateral support and no apparent flexion.
- Trunk flexed between 40° and 60°.
- The strength load is none, so, less than a kg.
- Forearm flexed between 60° and 100°.
- The movement of the wrist is between 0° and 15° of flexion/extension, without torsion produced.
- Arm flexion over 20°.
- Grip is considered good.

- It must be considered that the activity is repetitive without presenting an excessive physical effort, more over it doesn't has drastic changes in workers posture.

CUELLO

Movimiento	Puntuación	Corrección	
0°-20° flexión	1	Añadir + 1 si hay torsión o inclinación lateral	
>20° flexión o en extensión	2		

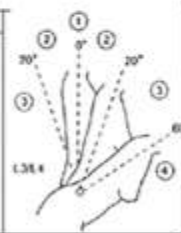
2

PIERNAS

Movimiento	Puntuación	Corrección	
Soporte bilateral, andando o sentado	1	Añadir + 1 si hay flexión de rodillas entre 30° y 60°	
Soporte unilateral, soporte ligero o postura inestable	2	Añadir + 2 si las rodillas están flexionadas + de 60° (salvo postura sedente)	

1

TRONCO

Movimiento	Puntuación	Corrección	
Erguido	1	Añadir + 1 si hay torsión o inclinación lateral	
0°-20° flexión 0°-20° extensión	2		
20°-60° flexión >20° extensión	3		
> 60° flexión	4		

3

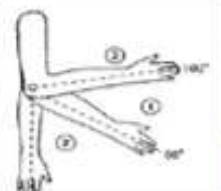
CARGA / FUERZA

0	1	2	+ 1	0
< 5 Kg.	5 a 10 Kg.	> 10 Kg.	Instauración rápida o brusca	

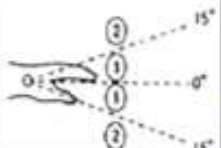
Figure 6. Posture 2: Group A evaluation.

The point section of the neck scores a value of 2 as it presents a flexion above 20°, legs a value of 1 because they are supported bilaterally and without an apparent flexion, trunk presents a score of 3 due a flexion between 20° and 60°, finally the user doesn't present a load or applied force, so that section has a value of 0.

ANTEBRAZOS

Movimiento	Puntuación	
60°-100° flexión	1	
flexión < 60° 0 > 100°	2	

MUÑECAS

Movimiento	Puntuación	Corrección	
0°-15° flexión/ extensión	1	Añadir + 1 si hay torsión o desviación lateral	
>15° flexión/ extensión	2		

BRAZOS

Posición	Puntuación	Corrección
0°-20° flexión/ extensión	1	Añadir: + 1 si hay abducción o rotación. + 1 si hay elevación del hombro. - 1 si hay apoyo o postura a favor de la gravedad.
>20° extensión	2	
flexión 20°-45°	2	
flexión 45°-90°	3	
>90° flexión	4	

AGARRE

0 - Bueno	1-Regular	2-Malo	3-Inaceptable	
Buen agarre y fuerza de agarre	Agarre aceptable	Agarre posible pero no aceptable	Incómodo, sin agarre manual inaceptable usando otras partes del cuerpo	

Figure 7. Posture 2: Group B evaluation.

The score section of forearms gets a value of 1 because they are flexed between 60° and 100°, wrists a value of 1 due a flexion range between 0° and 15°, arms score a value of 2 because a flexion above 20°, grip is considered good and gets a score of 0.

Grupo A: Análisis de cuello, piernas y tronco

PUNTUACIÓN CUELLO ⁽¹⁻³⁾ :	2
PUNTUACIÓN PIERNAS ⁽¹⁻⁴⁾ :	1
PUNTUACIÓN TRONCO ⁽¹⁻⁵⁾ :	3
PUNTUACIÓN CARGA/FUERZA ⁽⁰⁻³⁾ :	0

Grupo B: Análisis de brazos, antebrazos y muñecas

PUNTUACIÓN ANTEBRAZOS ⁽¹⁻²⁾ :	1
PUNTUACIÓN MUÑECAS ⁽¹⁻³⁾ :	1
PUNTUACIÓN BRAZOS ⁽¹⁻⁶⁾ :	2
PUNTUACIÓN AGARRE ⁽⁰⁻³⁾ :	0

Figure 8. Posture 2: Data summary

The result of the addition of values of group A is 6, while group B addition is 4. Next is a summary of posture evaluation.

NIVELES DE RIESGO Y ACCIÓN:	
Puntuación final REBA ⁽¹⁻¹⁵⁾	3
Nivel de acción ⁽⁰⁻⁴⁾	1
Nivel de riesgo	Bajo
Actuación	Puede ser necesaria la actuación

Figure 9. Posture 2: Risk levels and action

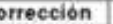
It's observed that the bean storage activity presents a lesser risk compared to the previous activity, however, even if it is a smaller risk, it would be ideal to implement actions to make this task more comfortable for workers, with a goal of a better performance and prevent any damage to their wellbeing.

Analized porsture for work: load and transportation of shell/beans seeds

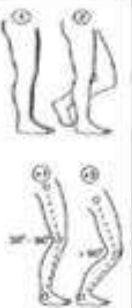
Data:

- Neck flexed between 0° and 20° in addition to presenting certain lateral inclination.
- Legs on bilateral support, without presenting flexion.
- Trunk erect.
- Load presented is over 10 Kg.
- Forearm flexed between 60° and 100°.
- The movement of the wrist is between 0° and 15° of flexion/extension, presenting torsion.
- Arm flexion over 90°.
- Grip is considered bad.
- The activity presents an uncomfortable posture, and a considerably high physical load for the worker.

CUELLO

Movimiento	Puntuación	Corrección	
0°-20° flexión	1	Añadir + 1 si hay torsión o inclinación lateral	
>20° flexión o en extensión	2		

2**PIERNAS**

Movimiento	Puntuación	Corrección	
Soporte bilateral, andando o sentado	1	Añadir + 1 si hay flexión de rodillas entre 30° y 60°	
Soporte unilateral, soporte ligero o postura inestable	2	Añadir + 2 si las rodillas están flexionadas + de 60° (salvo postura sedente)	

1**TRONCO**

Movimiento	Puntuación	Corrección
Erguido	1	Añadir + 1 si hay torsión o inclinación lateral
0°-20° flexión 0°-20° extensión	2	
20°-60° flexión >20° extensión	3	
> 60° flexión	4	

1

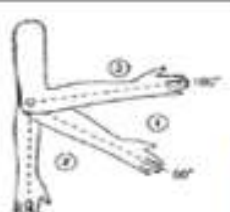
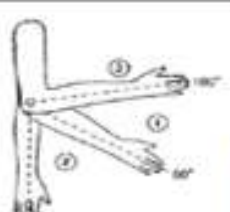
1**CARGA / FUERZA**

0	1	2	+ 1	
< 5 Kg.	5 a 10 Kg.	> 10 Kg.	Instauración rápida o brusca	

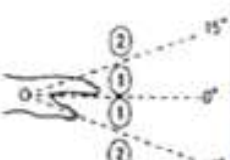
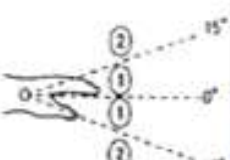
2Figure 10. Posture 3: *Group A evaluation.*

The point section of the neck scores a value of 2 as it presenting a flexion between 0° and 20° and a lateral inclination, legs a value of 1 because they are supported bilaterally and without an apparent flexion, trunk presents a score of 1 due it being erect, finally the load present is above 10 kg and scores a value of 2.

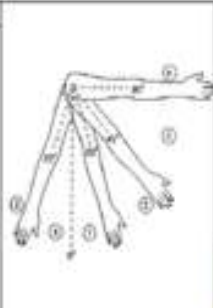
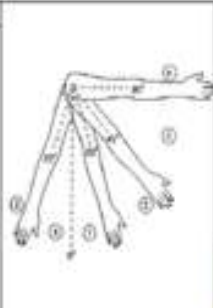
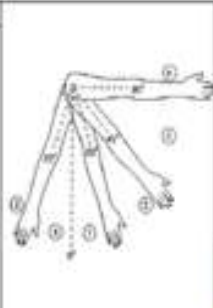
ANTEBRAZOS

Movimiento	Puntuación	
60°-100° flexión	1	
flexión < 60° 0 > 100°	2	

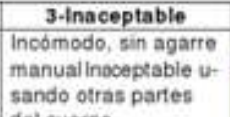
1**MUÑECAS**

Movimiento	Puntuación	Corrección	
0°-15° flexión/ extensión	1	Añadir + 1 si hay torsión o desviación lateral	
> 15° flexión/ extensión	2		

2**BRAZOS**

Posición	Puntuación	Corrección	
0°-20° flexión/ extensión	1	Añadir: + 1 si hay abducción o rotación.	
> 20° extensión	2	+ 1 si hay elevación del hombro.	
flexión 20°-45°	2	- 1 si hay apoyo o postura a favor de la gravedad.	
flexión 45°-90°	3		
> 90° flexión	4		

4**AGARRE**

0 - Bueno	1-Regular	2-Malo	3-Inaceptable	
Buen agarre y fuerza de agarre	Agarre aceptable	Agarre posible pero no aceptable	Incómodo, sin agarre manual inaceptable usando otras partes del cuerpo	

2

Figure 11. Posture 3: Group B evaluation.

The score section of forearms gets a value of 1 because they are flexed between 60° and 100°, wrists a value of 2 due a flexion range between 0° and 15° plus a torsion, arms score a value of 4 because a flexion above 90°, grip is considered bad and gets a score of 2.

Grupo A: Análisis de cuello, piernas y tronco

PUNTUACIÓN CUELLO⁽¹⁻³⁾:	2
PUNTUACIÓN PIERNAS⁽¹⁻⁴⁾:	1
PUNTUACIÓN TRONCO⁽¹⁻⁵⁾:	1
PUNTUACIÓN CARGA/FUERZA⁽⁰⁻³⁾:	2

Grupo B: Análisis de brazos, antebrazos y muñecas

PUNTUACIÓN ANTEBRAZOS⁽¹⁻²⁾:	1
PUNTUACIÓN MUÑECAS⁽¹⁻³⁾:	2
PUNTUACIÓN BRAZOS⁽¹⁻⁶⁾:	4
PUNTUACIÓN AGARRE⁽⁰⁻³⁾:	2

Figure 12. Posture 3: Data summary

The result of the addition of values of group A is 6, while group B addition is 9. Next is a summary of posture evaluation.

NIVELES DE RIESGO Y ACCIÓN:	
Puntuación final REBA⁽¹⁻¹⁵⁾	6
Nivel de acción⁽⁰⁻⁴⁾	2
Nivel de riesgo	Medio
Actuación	Es necesaria la actuación

Figure 13. Posture 3: Risk levels and action

This activity among the process of harvesting of beans is among ones that presents a bigger physical load, the principal setback of this is the lack of a transport system that doesn't involve the wear down of workers, as is, its necessary to take corrective measures.

Analized porsture for work: pounding of shell/beans seeds.

Data:

- Neck flexed between 0° and 20°.
- Legs on bilateral support, flexion above 60°.
- Trunk presents a flexion above 60°, plus, it presents certain torsion.
- Load presented is over 10 Kg, presenting a sudden unsaturation.
- Forearm flexed under 60°.
- The movement of the wrist over and 15° of flexion/extension, presenting a slight torsion.
- Arm flexion over 90°.

- Grip is considered bad.
- The evaluated activity presents a bigger physical load for the worker in comparison with the other activities in the harvesting process, moreover, it has a constant rhythm, generating a bigger physical wear down.

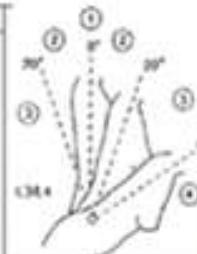
CUELLO

Movimiento	Puntuación	Corrección	
0°-20° flexión	1	Añadir + 1 si hay torsión o inclinación lateral	
>20° flexión o en extensión	2		

1**PIERNAS**

Movimiento	Puntuación	Corrección	
Soporte bilateral, andando o sentado	1	Añadir + 1 si hay flexión de rodillas entre 30° y 60°	
Soporte unilateral, soporte ligero o postura inestable	2	Añadir + 2 si las rodillas están flexionadas + de 60° (salvo postura sedente)	

3**TRONCO**

Movimiento	Puntuación	Corrección	
Erguido	1	Añadir + 1 si hay torsión o inclinación lateral	
0°-20° flexión 0°-20° extensión	2		
20°-60° flexión >20° extensión	3		
> 60° flexión	4		

5

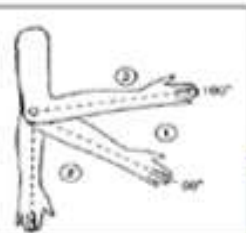
5**CARGA / FUERZA**

0	1	2	+ 1	3
< 5 Kg.	5 a 10 Kg.	> 10 Kg.	Instauración rápida o brusca	

Figure 14. Posture 4: Group A evaluation.

The point section of the neck scores a value of 1 as it presenting a flexion between 0° and 20°, legs a value of 3 because they are supported bilaterally and presents a flexion above 60°, trunk presents a score of 5 due a flexion above 60° plus torsion, the load present is above 10 kg and with a sudden unsaturation, scores a value of 3.

ANTEBRAZOS

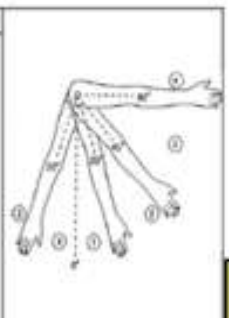
Movimiento	Puntuación	
60°-100° flexión	1	
flexión < 60° 0 > 100°	2	

2**MUÑECAS**

Movimiento	Puntuación	Corrección	
0°-15° flexión/ extensión	1	Añadir + 1 si hay torsión o desviación lateral	
>15° flexión/ extensión	2		

3

3**BRAZOS**

Posición	Puntuación	Corrección	
0°-20° flexión/ extensión	1	Añadir: + 1 si hay abducción o rotación.	
>20° extensión	2	+ 1 si hay elevación del hombro.	
flexión 20°-45°	2	-1 si hay apoyo o postura a favor de la gravedad.	
flexión 45°-90°	3		
>90° flexión	4		

4**AGARRE**

0 - Bueno	1-Regular	2-Malo	3-Inaceptable	
Buen agarre y fuerza de agarre	Agarre aceptable	Agarre posible pero no aceptable	Incómodo, sin agarre manual inaceptable usando otras partes del cuerpo	

2

Figure 15. Posture 4: Group A evaluation.

The score section of forearms gets a value of 2 because they are flexed under 100°, wrists a value of 3 due a flexion above 15° plus a torsion plus a slight torsion, arms score a value of 4 because a flexion above 90°, grip is considered bad and gets a score of 2.

Grupo A: Análisis de cuello, piernas y tronco

PUNTUACIÓN CUELLO ⁽¹⁻³⁾ :	1
PUNTUACIÓN PIERNAS ⁽¹⁻⁴⁾ :	3
PUNTUACIÓN TRONCO ⁽¹⁻⁵⁾ :	5
PUNTUACIÓN CARGA/FUERZA ⁽⁰⁻³⁾ :	3

Grupo B: Análisis de brazos, antebrazos y muñecas

PUNTUACIÓN ANTEBRAZOS ⁽¹⁻²⁾ :	2
PUNTUACIÓN MUÑECAS ⁽¹⁻³⁾ :	3
PUNTUACIÓN BRAZOS ⁽¹⁻⁶⁾ :	4
PUNTUACIÓN AGARRE ⁽⁰⁻³⁾ :	2

Figure 16. Posture 4: Data summary

The result of the addition of values of group A is 12, while group B addition is 11. Next is a summary of posture evaluation.

NIVELES DE RIESGO Y ACCIÓN:	
Puntuación final REBA⁽¹⁻¹⁵⁾	12
Nivel de acción⁽⁰⁻⁴⁾	4
Nivel de riesgo	Muy alto
Actuación	Es necesaria la actuación de inmediato

Figure 17. Posture 4: Risk levels and action

As it can be observed in the obtained results, the activity presents a high risk level, due the physical load and postures it entails, its necessary an immediate corrective action with the goal to prevent physical afflictions that put the health of workers at risk.

Activity	Final score	Action level	Risk level
Bean collecting	8	3	High
Bean storage	3	1	Low
Load and transportation	6	2	Mid
Bean pounding	12	4	Very High

Table 1. REBA methodology results

Once evaluated the main activities on the process of bean harvesting, it can be observed with clarity that two of these activities present a high risk level, and being done for extended periods of time it can affect on a significant way the workers health.

Therefore, corrective measure must be applied as soon as possible, to prevent any kind of musculoskeletal injury or ailment that compromises workers well being.

4. CONCLUSIONS

Bean harvesting is one of the activities with the biggest impact on Mexican population, due the quantity of employment this generates, the consuming of this food by the same population and the economic flow generated by its exportation.

The present project analyzed and evaluated in an ergonomic way the process of bean harvesting, noting this task generates a considerable physical wear down to the people that perform it, taking toll in their health and wellbeing if continuing so in the same way.

Its because that a development of a dispositive to facilitate the harvesting of bean is proposed, beside of offering workers a work system that represents a smaller physical load and a better effectiveness.

For this dispositive implementation, measurements and testing are necessary that let us know the anatomic measurements of the population that is focused on, with the use of anthropometric tool a representative sample was sampled, those values were also analyzed statistically with the goal of determining if they were representative or not, and calculate their basic statistics.

These results let us adapt a design of the mechanism to the destined user, taking in account their anatomic measurements reaching an adjustment interval, that presents a better comfort for the user and a better performance in their task.

After finishing both evaluations, its concluded that its necessary a change in the harvesting process of beans, which will be improved with the implementation with a dispositive in development. Which, once implemented, could be evaluated in the same way that the manual process, making an effectiveness comparison between the two.

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