Force analysis in hands on highly repetitive work in maquila operations

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Resumen: Esta investigación se enfoca a analizar la fuerza como una función de tiempo en datos obtenidos en condiciones reales, considerando trabajo altamente repetitivo, donde las manos y dedos están expuestos a trabajo repetitivo y bajos esfuerzos. Se utilizo el diseño genera de medidas repetidas para analizar el comportamiento de la fuerza para ambas manos y pulgares. La hora, el turno y el día de trabajo fueron considerados como factores. La fuerza fue medida de la sexta a la octava hora en un intervalo de una hora, mientras que la semana empezó el lunes; el monitoreo fue de una semana. Los datos fueron obtenidos de plantas maquiladoras de las ciudades de Hermosillo y Nogales Sonora.

Palabras Calve: Fuerza en manos, fuerza en pulgares, trabajo repetitivo, efecto acumulado de la fuerza, maquila.

Abstract: The focus of this research is analyze how force is going as a function of time in data obtained from real work conditions, considering highly repetitive work, where the hands and fingers are exposed to repetitive work and low efforts. The repetitive measurement general design was used to analyze force behavior for both hands and both thumbs. The hour on the shift and the day week are the factors. Force was measured from the sixth hour to the eight hour on one hour interval, while the week day starts on Monday; the monitor is for a week. Data were obtained on maquila plants in Hermosillo and Nogales Sonora.

Keywords: Hands force, thumbs force, repetitive work, cumulative effect of force, maquila.

1. Introduction

The work doing by the hands has been a very important factor on manufacturing industries, especially on development countries, but the human being and its physical characteristics at service of material transformation on industrial process it is not an endless power supply, while time passthrough the day, physical performance could be affected and modified.

As a result of frequent exposure to work there is a risk of musculoskeletal injuries, Bernard et al (1997) refers that it´s "were recognized as having occupational etiologic factors as early as the beginning of the 18th century,however, it was not until the 1970s that occupational factors were examined using epidemiologic methods, and the work-relatedness of these conditions began appearing regularly in the international scientific literature. Since then the literature has increased dramatically; more than six thousand scientific articles addressing ergonomics in the workplace have been published. Yet, the relationship between MSDs and work-related factors remains the subject of considerable debate."

To understand the musculoskeletal disorders problem, is required to identify the risk factors associated to these kinds of injuries. There is a wide literature about it and its don´t surprise, the problem has been studied for years and many point of views and results of research converge on the causes or risk factors, Colombini (1998) recognize mainly four risk factors; repetitive movements (frequency), force applied to the task, awkward postures and lack of enough recovery time on each work cycle. Muggleton (1999) includes vibration as a risk factor for the hand-wrist. McAtamney y Corlet (1973) refers to the risk factors as external factors, including a consideration for static work load on muscles. Furthermore, highly repetitive work may directly damage tendons through repeated stretching and elongation, as well as increase the likelihood of fatigue and decrease the opportunity for tissues to recover Keyserlin et al (1993).

This work is focused in finding the relationship between frequency and the force that people can exert as a function of time and some anthropometric characteristics, the approach is; on the latest hours of the shift work, force become to decrease significant, at least statistically and there is a relationship between force and anthropometrics.

2. Method

One objective was collect data in working conditions, so the "experiment" was planned as follows:

- Find a process with highly repetitive operations; it is more than 300 units per hour.
- The job involves extensive use of the hands and the fingers.
- The anthropometrics measurements are for the hands and some generals:
    - Length of the hand.
    - Width of the hand.
    - Height of the hand.
    - Width of the wrist
    - Height of the wrist
    - Height of the thumb
    - Width of the thumb
    - Height of the middle finger
    - Width of the middle finger
- The force on handgrip and thumb grip is measure with a Jamar© hand dynamometer and finger dynamometer. Every day 3 measurements are made every half hour from the sixth hour for the handgrip and finger grip for each side of the hands.
- All data is collected and analyzed on statistical software (SPSS©)
- Multiple linear regression is the tool to analyze the relationship between force and anthropometrics.
- The repetitive measurements general model is used to analyze the force within hours and within days.
- The data are from maquilas on Hermosillo and Nogales, Sonora, Mex.

3. Results

Is relevant to mention, again, how important get data from working conditions is, there was about 50 operators who they were asked for to participate with the measurements for anthropometrics and force exertions, we appreciate that very much as well the maquila support to achieve the purpose of the research. Once data were collected and organized on worksheets next step is proceed to statistical analysis.

The first part is finding the relationship between anthropometrics and force for each side on the hands, before the linear regression analysis, principal components was run to discriminate and

group variables, the next tables show it:The first iteration includes all variables resulting on seven groups and .717 acceptable KMO value, results are:

Table 1. Total variance explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.254	34.545	34.545	7.254	34.545	34.545	4.218	20.084	20.084
2	2.289	10.898	45.442	2.289	10.898	45.442	3.496	16.646	36.730
3	2.027	9.654	55.096	2.027	9.654	55.096	2.965	14.118	50.849
4	1.432	6.818	61.914	1.432	6.818	61.914	1.765	8.404	59.253
5	1.170	5.572	67.486	1.170	5.572	67.486	1.377	6.559	65.812
6	1.114	5.303	72.789	1.114	5.303	72.789	1.275	6.072	71.884
7	1.041	4.959	77.748	1.041	4.959	77.748	1.232	5.864	77.748
8	.799	3.804	81.552						
9	.757	3.603	85.155						
10	.567	2.701	87.856						
11	.500	2.380	90.236						
12	.463	2.207	92.443						
13	.402	1.914	94.357						
14	.298	1.420	95.777						
15	.249	1.184	96.961						
16	.179	.852	97.813						
17	.151	.720	98.533						
18	.107	.507	99.041						
19	.079	.378	99.419						
20	.065	.310	99.729						
21	.057	.271	100.000						

Extraction Method: Principal Component Analysis.

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The first rotated component matrix shows how variables are grouped in the seven groups:

Table 2 Rotated Component Matrix

	Component						
	1	2	3	4	5	6	7
GEN	.066	.824	.334	-.133	.084	.072	-.106
EDAD	.030	-.148	-.856	.005	.135	-7.904E-5	-.072
EST	.171	.711	.322	-.079	.181	.166	.095
PESO	.033	.391	.697	-.089	-.048	.051	-.081
ANGHOM	-.023	-.256	-.134	-.124	.023	-.838	.013
ANGMANO	-.336	-.283	-.169	-.272	-.289	.216	.579
GRUEMANO	.167	.021	.053	.156	.081	-.123	.877
LONGMAN	.419	.407	.189	.088	.224	.048	.056
LONDEM	.802	.374	.096	-.009	.108	.094	.025
ANCHMAN	.667	.489	.349	.054	-.063	-.173	.045
LONGPUL	.407	.638	-.138	.097	-.032	.204	-.054
ANCHPUL	.904	.121	.056	.040	.096	.091	.054
ANCHDEDMED	.879	.106	.067	.012	-.132	-.007	.008
ANCHMUNEC	.505	.585	.159	.224	-.067	-.169	-.094
ALTMUN	.521	-.330	-.013	.166	.130	.491	-.214
LONGHOM	.137	.269	-.053	-.045	.854	.070	.019
LONGBRAZO	.434	.387	.211	.057	-.587	.175	.065
TREC	-.165	-.002	-.487	-.757	.153	-.200	-.031
FATPERC	-.002	-.003	-.115	.931	.022	.057	.053
SEVERIDAD	.438	.002	.759	.222	.060	.182	.017
FUERZA	.263	.584	.623	.162	.105	-.059	-.141

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 9 iterations.

After several iterations, the target is find two groups; this final rotated matrix is next:

Table 3 Final Rotated Component Matrix

	Component	
	1	2
GEN	.888	.019
EST	.790	.135
PESO	.753	.008
LONDEM	.384	.773
ANCHMAN	.631	.627
ANCHPUL	.182	.899
ANCHDEDMED	.159	.866
ANCHMUNEC	.626	.486
ALTMUN	-.215	.620
SEVERIDAD	.454	.477
FUERZA	.860	.239

As values are shown on the table 4.3 the groups are formed with the higher coefficients; a first group is for; gender, height, weight and hand force. The second group are formed with; hand length, hand width, thumb width, thumb length and wrist width.

Once groups are formed the next is linear regression analysis, the purpose here is just to found some kind of statistical relationship between variables or personal and force, next table shows the better relationship:

Table 4 Linear Regression Model

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.804[a]	.647	.576	19.32408

a. Predictors: (Constant), ALTMUN, EST, ANCHDEDMED, PESO, ANCHMUNEC, LONDEM, GEN, ANCHPUL

b. Dependent Variable: FUERZA

Predictor variables were; height, weight, thumb width, wrist width and hand length. Response variable is hand force.

Linear regression shows a relationship between variables and force, that in general conditions, so next step is the analysis of force as a function of time.

Force behavior was tested using repetitive measurements general model for each hand. Additionally some extra test was run in order to probe variances and differences between hours and days. Results are in next tables. The first test is for right hand and the hour of the shift, table 5 shows descriptive and table 6 shows Mauchy´s sphericity test.

Table 5.Descriptive statistics for right hand and hour

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Estadísticos descriptivos

	Media	Desviación típica	N
H6MD	43.5824	27.44422	296
H65MD	42.8402	27.52027	296
H7MD	42.8470	28.45860	296
H75MD	42.1193	28.02965	296
H8MD	43.2957	28.50338	296

Table 6.Mauchy´ssphericity test

Prueba de esfericidad de Mauchly[b]

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Medida:MEASURE_1

Efecto intra-sujetos	W de Mauchly	Chi-cuadrado aprox.	gl	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Límite-inferior
HORAMD	.845	49.581	9	.000	.919	.932	.250

Significance on Mauchy´s test is 0.00 that means differences between variances are not equals, so is necessary run the Bonferronistest for multiple comparisons, this test shows in what hour are a difference in average exerted force on right hand, table 7 shows it.

Same proceed is for the left hand and next tables shows results for descriptive statistics, significance on Mauchy´s test is 0.00 that means differences between variances are not equals, so is necessary again run the Bonferronis test for multiple comparisons, this test shows in what hour are a difference in average exerted force on left hand.

All statistical tests are for a 95% confidence level.

Table 7.Bonferroni´s pair comparisons for right hand

Comparaciones por pares

Medida:MEASURE_1

(I)HORAMD	(J)HORAMD	Diferencia de medias (I-J)	Error típ.	Sig.[a]	Intervalo de confianza al 95 % para la diferencia[a]	
					Límite inferior	Límite superior
1	2	.742	.377	.501	-.325	1.809
	3	.735	.432	.899	-.487	1.958
	4	1.463*	.453	.014	.181	2.746
	5	.287	.509	1.000	-1.152	1.726
2	1	-.742	.377	.501	-1.809	.325
	3	-.007	.432	1.000	-1.229	1.215
	4	.721	.465	1.000	-.593	2.035
	5	-.455	.523	1.000	-1.934	1.023
3	1	-.735	.432	.899	-1.958	.487
	2	.007	.432	1.000	-1.215	1.229
	4	.728	.427	.897	-.481	1.937
	5	-.449	.479	1.000	-1.802	.905
4	1	-1.463*	.453	.014	-2.746	-.181
	2	-.721	.465	1.000	-2.035	.593
	3	-.728	.427	.897	-1.937	.481
	5	-1.176	.483	.155	-2.543	.191
5	1	-.287	.509	1.000	-1.726	1.152
	2	.455	.523	1.000	-1.023	1.934
	3	.449	.479	1.000	-.905	1.802
	4	1.176	.483	.155	-.191	2.543

Basadas en las medias marginales estimadas.

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Table 8.Descriptive for left hand

Estadísticos descriptivos

	Media	Desviación típica	N
H6MI	42.5443	26.22754	296
H65MI	41.5257	26.27132	296
H7MI	42.0186	26.73049	296
H75MI	42.1520	26.48484	296
H8MI	41.7490	26.25596	296

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Table 9.Mauchy´s test for left hand.

Prueba de esfericidad de Mauchly[b]

Medida:MEASURE_1

Efecto intra-sujetos	W de Mauchly	Chi-cuadrado aprox.	gl	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Límite-inferior
HORAMI	.170	520.466	9	.000	.479	.482	.250

Table 10.Bonferroni´s pair comparison for left hand.

Comparaciones por pares

Medida:MEASURE_1

(I)HORAMI	(J)HORAMI	Diferencia de medias (I-J)	Error típ.	Sig.[a]	Intervalo de confianza al 95 % para la diferencia[a]	
					Límite inferior	Límite superior
1	2	1.019	.410	.135	-.140	2.177
	3	.526	.477	1.000	-.823	1.874
	4	.392	.838	1.000	-1.977	2.762
	5	.795	.886	1.000	-1.712	3.302
2	1	-1.019	.410	.135	-2.177	.140
	3	-.493	.484	1.000	-1.862	.876
	4	-.626	.856	1.000	-3.048	1.795
	5	-.223	.917	1.000	-2.818	2.372
3	1	-.526	.477	1.000	-1.874	.823
	2	.493	.484	1.000	-.876	1.862
	4	-.133	.825	1.000	-2.466	2.199
	5	.270	.889	1.000	-2.244	2.783
4	1	-.392	.838	1.000	-2.762	1.977
	2	.626	.856	1.000	-1.795	3.048
	3	.133	.825	1.000	-2.199	2.466
	5	.403	.483	1.000	-.963	1.769
5	1	-.795	.886	1.000	-3.302	1.712
	2	.223	.917	1.000	-2.372	2.818
	3	-.270	.889	1.000	-2.783	2.244
	4	-.403	.483	1.000	-1.769	.963

Same proceed is for both hands but the analysis is now within week days. Next tables shows results for descriptive statistics, significance on Mauchy´s test is 0.00 that means differences between variances are not equals, so is necessary again run the Bonferronis test for multiple comparisons, this test shows in what day are a difference in average exerted force the hand.

Table 11.Mauchy´s test for day and right hand

Prueba de esfericidad de Mauchly[b]

Medida:MEASURE_1

Efecto intra-sujetos	W de Mauchly	Chi-cuadrado aprox.	gl	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Límite-inferior
DIAMD	.176	510.141	9	.000	.622	.627	.250

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Right hand force descriptive are:

Table 12.Descriptive statistics for right hand and day.

Estimaciones

Medida:MEASURE_1

DIAMD	Media	Error típ.	Intervalo de confianza 95%	
			Límite inferior	Límite superior
1	43.569	1.699	40.225	46.913
2	44.523	1.680	41.216	47.830
3	43.103	1.636	39.884	46.322
4	42.765	1.621	39.576	45.955
5	40.021	1.527	37.016	43.025

Table 13.Bonferroni´s comparison pair test

Comparaciones por pares

Medida:MEASURE_1

(I)DIAMD	(J)DIAMD	Diferencia de medias (I-J)	Error típ.	Sig.[a]	Intervalo de confianza al 95 % para la diferencia[a]	
					Límite inferior	Límite superior
1	2	-.954	.813	1.000	-3.253	1.345
	3	.466	1.540	1.000	-3.888	4.821
	4	.804	.574	1.000	-.819	2.427
	5	3.548	1.718	.398	-1.312	8.409
2	1	.954	.813	1.000	-1.345	3.253
	3	1.420	1.616	1.000	-3.151	5.992
	4	1.758	.919	.568	-.842	4.357
	5	4.502	1.718	.092	-.355	9.360
3	1	-.466	1.540	1.000	-4.821	3.888
	2	-1.420	1.616	1.000	-5.992	3.151
	4	.338	1.549	1.000	-4.043	4.718
	5	3.082	1.650	.628	-1.585	7.749
4	1	-.804	.574	1.000	-2.427	.819
	2	-1.758	.919	.568	-4.357	.842
	3	-.338	1.549	1.000	-4.718	4.043
	5	2.745	1.726	1.000	-2.138	7.628
5	1	-3.548	1.718	.398	-8.409	1.312
	2	-4.502	1.718	.092	-9.360	.355
	3	-3.082	1.650	.628	-7.749	1.585
	4	-2.745	1.726	1.000	-7.628	2.138

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Table 14.Mauchy´s test for day and left hand

Prueba de esfericidad de Mauchly[b]

Medida:MEASURE_1

Efecto intra-sujetos	W de Mauchly	Chi-cuadrado aprox.	gl	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Límite-inferior
DIAMI	.426	250.281	9	.000	.723	.731	.250

Table 15. Descriptive statistics for left hand and day

Estimaciones

Medida:MEASURE_1

DIAMI	Media	Error típ.	Intervalo de confianza 95%	
			Límite inferior	Límite superior
1	44.356	1.626	41.156	47.557
2	43.121	1.586	40.000	46.242
3	41.325	1.539	38.296	44.353
4	42.007	1.503	39.049	44.966
5	38.337	1.419	35.544	41.130

Table 15.Bonferroni´s comparison pair test for left hand and day.

Comparaciones por pares

Medida:MEASURE_1

(I)DIAMI	(J)DIAMI	Diferencia de medias (I-J)	Error típ.	Sig.[a]	Intervalo de confianza al 95 % para la diferencia[a]	
					Límite inferior	Límite superior
1	2	1.236	.964	1.000	-1.490	3.962
	3	3.032	1.465	.394	-1.113	7.176
	4	2.349	.895	.092	-.184	4.882
	5	6.019*	1.652	.003	1.346	10.692
2	1	-1.236	.964	1.000	-3.962	1.490
	3	1.796	1.542	1.000	-2.565	6.157
	4	1.113	.881	1.000	-1.380	3.606
	5	4.783*	1.571	.025	.339	9.228
3	1	-3.032	1.465	.394	-7.176	1.113
	2	-1.796	1.542	1.000	-6.157	2.565
	4	-.683	1.451	1.000	-4.785	3.420
	5	2.988	1.544	.540	-1.380	7.355
4	1	-2.349	.895	.092	-4.882	.184
	2	-1.113	.881	1.000	-3.606	1.380
	3	.683	1.451	1.000	-3.420	4.785
	5	3.670	1.521	.164	-.631	7.972
5	1	-6.019*	1.652	.003	-10.692	-1.346
	2	-4.783*	1.571	.025	-9.228	-.339
	3	-2.988	1.544	.540	-7.355	1.380
	4	-3.670	1.521	.164	-7.972	.631

4. Discussion

In an implicit form the purpose of this research was to show how force depend on anthropometric characteristics and how force is related with fatigue with a clear decrease pattern on force behavior trough hours and days.

The first part tested by principal components and linear regression is positive; a statistical relationship does exist between hand and finger anthropometrics and force, in detail table 3 shows that, all values on above .600 on second group are related with the explanation of variance.

In the second part the expected was that the greater values for hand forces were on the early hour and Monday, but results are not in that direction, for right hand force within hours, table 7 shows a difference only between the first hour of the test and 2.5 hours later. For left hand there is not statistical evidence that shows how force decrease in function of time.

For hand force behavior related to day week, due to more than 90% of people are right-handed, the expected force behavior is that on Monday are the greater averages while on Friday should be the smaller averages. Table 12 shows that there is not any significative difference on right hand force average. For left hand force average, respect to Monday is valid a decreasing force behavior but statistically is valid only to Friday, on Tuesday the difference on average is only respect to Friday. The other days remain the same.

As a final conclusion on this research the findings is that force has not a decreasing behavior due to hours or days, it makes necessary to increase the number of measurements and run a test for the thumb force.

This fact, no decreasing force behavior should be not assumed as a fatigue free operations, while data were collected people says how at the end of the day they are with symptoms of pain and numbness on fingers, wrist, shoulder, neck and low back. Highly repetitive operations may have not an effect on force but that does not means that is an easy job.

In maquilas, there is a lot of situations that should be improved, beyond manufacturing and quality is the human being, it is not only manpower, they are people and deserve a good place to workon.

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