Workload Assessment Techniques for Job Design

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Why Assess Workload???

40% of American workers reported their Job is "Very or Extremely Stressful."

-Northwestern National Life

25% of workers perceive work as their Largest Life Stress

-Northwestern National Life

Why Assess workload??

In a 1999 study of 46,000 workers, health care costs were 147% higher in workers who were stressed or depressed than in others who were not

- Health and Age

What is Workload?

- **Physiological and mental demands that occur while performing a task or a combination of tasks.**

- **Workload is defined as the physical and/or mental requirements associated with a task or combination of tasks.**

What is Workload?

- Aspect of Interaction between an operator and an Assigned Task

- The term workload refers to that portion of the operators limited capacity actually required to perform a particular Task

Tasks are specified in terms of their structural properties. A set of stimuli and responses are specified with a set of rules that map responses to stimuli.

Workload can be classified as:

- ✓**Physical Workload**
- ✓**Mental Workload**

Physical Workload

- **Physical workload is the measurable portion of physical resources expended when performing a given task and is affected by a range of factors.**

- **Factors include Nature of work, Training, Motivation and Environmental Factors**

Subjective Measures for Physical Workload

- An Individuals Subjective reports of perception associated with physical work can be used to obtain information about physiological responses to work and workload level
- These Assessment tools incorporate the use of scaling techniques,which vary in structure and complexity

Subjective Assessment Tools

- ***Armstrong et al.(1989)*** **asked participants to rate their perceptions of grip force, tool mass and handle size on a continuous linear scale from '0 to 10'**

- **Borg Rating of Perceived Exertion (RPE) Scale and Borg CR-10 scale[*Borg, G., and Linderholm, H. (1970); Borg, G.(1985)*]**

Subjective Assessment Tools

- **Body Diagrams – The Nordic Questionnaire [*Kroemer et al.(1994)*]**
- **Pain Estimation Charts- The McGill Pain Questionnaire [*Melzack(1975*)]**
- **Visual Analog (VA) Scales [*Neely et al.(1992)*]**

Objective Measures of Physical Workload

- **Energy Capacity(The Physiological Approach)**

  -Evaluating the Energy Cost of performing an Activity

- **Biomechanical(Biomechanical Analysis of Workload)**

  -Evaluating stress on Musculoskeletal system

ENERGY CAPACITY (The Physiological Approach)

- Energy Cost
- Heart Rate
- Blood Pressure
- Blood Lactate Level

Energy Cost

- Karvonen (1974) reported metabolic rates of various occupational activities:

Sitting Crane Operator	:	3.37 Kcal/min
Light Welding	:	4.04 Kcal/min
Walking	:	5.39 Kcal/min
Arm lifting(20-44lb)	:	6.06 Kcal/min
(45-64lb)	:	8.08 Kcal/min
(65-84lb)	:	11.45 Kcal/min
Hammering, Sawing	:	8.08 Kcal/min

Energy Cost

- Muller(1953) and Bink(1962) proposed the upper limit of the energy expenditure required for daily work should be 5-5.2 kcal/min
- Michael et al.(1961) reported that 35% of the maximum aerobic capacity (VO_2 max) was the limit of work that could be performed without undue fatigue

Heart Rate

- Several Investigators have recommended a heart rate rage between 99-130 beats/min.

- Brouha (1967); Suggs and Splinter (1961) recommended that the mean heart rate should not exceed 115 beats/min

Heart Rate

- Snook and Irvine (1969) suggested a limit of 112 beats/min for leg tasks and 99 beats/min for arm tasks in a more conservative estimate on the mean Heart rate criterion

Blood Pressure

- Astrand and Rodhal (1977) concluded that the blood pressure was significantly higher in arm exercise than in leg work
- In Isometric activity, the intrathoracic pressure is raised form 80-200 mm Hg or more causing a sharp increase in Systolic and Diastolic BP

Blood Lactate Level

- Petrofsky and Lind(1978a,b) reported a limit of 50% of aerobic lifting capacity.This limit was equivalent to 25% aerobic capacity determined by a bicycle ergometer.

BIOMECHANICAL APPROACH

- **Occupational Biomechanics applies principles of biomechanics towards work improving everyday activities,especially dealing with human disorders and performance limitations which exists in a variety of manual tasks in Industry**

BIOMECHANICAL APPROACH

- Stress on Musculoskeletal System
- Stress on Lumbosacral Spine
- Biomechanical Design Criteria

Mental Workload

- **No clear consensus….“Mental Workload is intrinsically complex and multifaceted”[*Jex (1988)*]**

- **An Attribute of Information processing and control systems that mediate between stimuli and, rules and responses. [*Gopher, D., and Donchin, E. (1986)*]**

Mental Workload

- **An attribute of person-task loop, and the effects of workload on human performance [*Gopher, D., and Donchin, E. (1986)*]**

Factors Affecting Mental Workload

- Research is still in progress to clearly define the factors that affect Mental Workload

Measurement Techniques

1. **Subjective Measures that include subject's estimation of workload.**

2. **Performance Measures (e.g. Reaction time, Number correct, and Number detected)**

Measurement Techniques

3. **Physchophysiological Measures (e.g. Heart rate, Heart rate variability, and Brain activity),**

4. **Analytical Measures**

1. SUBJECTIVE MEASURES

- **Based on Operator Rating of the Task**
- **Involves Judgement of effort.**
- **Reflect the direct opinion of the operator in context of the Task environment and skill and experience level of the operator**

Subjective Assessment Approaches

- **Rating Scale**

- **Unidimensional or Multidimensional**
- **Immediately or Retrospective**
- **Absolute or Relative**

Subjective Rating Instruments

- SWORD(Subjective Workload Dominance)
- Bedford
- MCH (Modified Cooper Harper)
- Psychophysical

Subjective Rating Instruments

- NASA-TLX (Task Loading Index)
- SWAT (Subjective workload Assessment Techniques)
- Workload Profile

BEDFORD

- Developed for application to flight environment.
- Based on Judgement of spare information processing capacity and workload.

The BEDFORD Rating Scale

Workload Description	Rating
Workload Insignificant	WL 1
Workload Low	WL 2
Enough spare capacity for all desirable additional task	WL 3

The BEDFORD Rating Scale

Insufficient spare capacity for easy attention to additional tasks	WL 4
Reduced spare capacity: additional tasks cannot be given the desired amount of attention	WL5
Little Spare capacity: Level of effort allows little attention to additional tasks	WL6

The BEDFORD Rating Scale

Very Little spare capacity, but maintenance of effort in the primary task not in question	WL 7
Very High workload with almost no spare capacity.Difficult in maintaining level of effort	WL 8
Extremely High workload. No spare capacity. Serious doubts as to ability to maintain level of effort	WL 9

The BEDFORD Rating Scale

Task Abandoned. Pilot unable to apply sufficient effort	WL 10

MCH

- Developed for Applications beyond aircraft environment. Hence more generic to Operator Mental Effort.

  Measured on a 10 point scale

MCH Rating Scale

Difficulty Level	Operator Demand Level	Rating
Very Easy, Highly Desirable	Operator Mental Effort is minimal and Desired Performance is easily attainable	1
Easy, Desirable	Operator Mental Effort is low and Desired performance is attainable	2
Fair, Mild Difficult	Acceptable Operator Mental Effort is required to attain adequate system performance	3

MCH Rating Scale

Minor But Annoying Difficulty	Moderately high operator mental effort is required to attain adequate system performance	4
Moderately Objectionable Difficulty	High operator mental effort is required to attain adequate system performance	5
Very Objectionable but tolerable difficulty	Maximum operator mental effort is required to attain adequate system Performance	6

MCH Rating Scale

Major Difficulty	Maximum operator mental effort is required to bring errors to moderate level	7
Major Difficulty	Maximum operator mental effort is required to avoid large or numerous errors	8
Major Difficulty	Intense operator mental effort is required to accomplish task, but frequent or numerous errors persist	9

MCH Rating Scale

Impossible	Instructed task could not be accomplished reliably	10

NASA TLX

- **NASA TLX (Task Load Index) subscales are:**

  Mental demand, Physical Demand, Temporal demand, Performance, Effort and Frustration Level

NASA TLX Rating Scale Definition

Title	End Points	Description
Mental Demand	Low/High	How much mental and perceptual activity was required(e.g., thinking, deciding, calculating, remembering, looking searching, etc)?Was the Task Easy or demanding, simple or complex, exacting or forgiving
Physical Demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)?Was the Task easy or demanding, slow or brisk, slack or strenuous, restful or laborious

NASA TLX Rating Scale Definitions

Temporal Demand	**Low/High**	**How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?**
Performance	**Good/poor**	**How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?**
Effort	**Low/High**	**How hard did you have to work(mentally and physically)to accomplish your level of performance**

NASA TLX Rating Scale Definitions

Frustration Level	**Low/High**	**How insecure, discouraged, irritated, stressed and annoyed versus secure,gratified, content, relaxed and complacent did you feel during the task?**

SWAT

- **SWAT (Subjective Workload Assessment Techniques) subscales are:**

  Time Load, Mental Effort Load and Psychological Stress Load

SWAT Rating Scale Dimension

I. **Time Load:**

1. **Often have spare time. Interruptions or overlap among activities occur infrequently or not at all**
2. **Occasionally have spare time. Interruptions or overlap among activities occur frequently**
3. **Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time**

SWAT Rating Scale Dimensions

II. Mental Effort Load:

1. Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.
2. Moderate or Conscious mental effort or concentration required. Complexity of activity is moderately high.
3. Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

SWAT Rating Scale Dimensions

III. Psychological Stress Load:

1. Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

2. Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

3. High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required

Comparison

	Approaches		
Subjective Rating Instruments	Unidimensional (U) Vs Multidimensional (M)	Absolute (A) Vs Relative (RS)	Immediate (I) Vs Retrospective (R)
Bedford	U	A	I
MCH	U	A	I or R
Psychophysical	U	RS	R
SWORD	U	RR	R
NASA-TLX	M	A	I
SWAT	M	A	I
Workload Profile	M	A	R

Measurement Issues

- Can be used as Projective Measures
- High Face Validity and Widespread Operator Acceptance
- Ease of Use
- Sensitive to a variety of information in working memory

Measurement Issues

- **Provide Diagnostic Information**
- **Reliable and Have sufficient concurrent validity**
- **Fail to reflect the demand of the individual components of multiple tasks.**

Drawbacks

- A 48 hr delay in response would result in memory loss and thus alters the ratings
- Maybe susceptible to operator bias
- Ego can be a factor
- Potential to Dissociate with the other types of workload measures

2. PERFORMANCE MEASURES

- **Uses operator behavior to determine workload**
- **Deteriorated and/or erratic performance may indicate that the worker is at or is approaching unacceptable levels**
- **Primary Task Method: Actual operator system is monitored with changes in demand**

PERFORMANCE MEASURES

- Secondary task method could be used where primary task is difficult to obtain or not available

- Operator is required to perform a secondary task concurrently with the primary task of interest

Some Tools

- AGARD STRESS Battery
- Choice Reaction Time
- Criterion Task Set
- Multi-Attribute Task Battery
- Time Estimation/Interval Production
- Mental Arithmetic

Choice Reaction Time Tasks

- Kantowitz et al(1983) used a three-choice variant of secondary reaction time task in an experiment that manipulated difficulty between conditions by systematically imposing different concurrent flight task on pilot

Choice Reaction Time Task

- Low-difficulty (Maintain Altitude), Moderate difficulty (Concurrently Maintain altitude, maintain airspeed) and High difficulty condition had concurrent performance of three flight tasks
- Tones associated with secondary choice reaction time task were presented at regular intervals

Choice Reaction Time Tasks

- Secondary task performance , as indexed by transmitted information, reliably distinguished the difficulty associated with the different primary flight conditions
- No intrusion by secondary task was reported
- Hence Choice Reaction Time Tasks could serve as effective secondary task under multi-task conditions in flight scenarios

Time Estimation and Interval Production

- **Time estimation paradigms require the subject to judge or estimate the passage of a specific interval of time**
- **Interval production task requires the subject to generate a series of regular time intervals through a motor response, such as finger or foot tapping.**

Time Estimation and Interval Production

- **Time estimation techniques have been proved more sensitive to the demand manipulations used in the series of flight experiments(Casali and Wierwille , 1983, 1984; Wierwille et al.,1985) that were of Central Processing(Solve navigation problems)**

Time Estimation and Interval Production

- **Interval Production task may represent a sensitive approach to assessment of workload in tasks which involve a high degree of motor output(e.g.,Manipulate a series of switches) loading.**

Mental Arithmetic Tasks

- Used in Multi task situations related to both flight and driving environments
- Different levels of workload are presented and a mental arithmetic task is presented during each level of workload auditorily and the operator is required to report the answers

Mental Arithmetic Tasks

- Did not show intrusion of secondary task on primary task
- Capability to discriminate levels of load
- Difficult to identify a factor or factors that might be responsible for the somewhat mixed sensitivity results

Measurement Issues

- Most direct Objective Measure
- Sensitive to a variety of task demands
- Very Reliable
- Advantage of secondary task is its diagnostic value and selective sensitivity

Drawbacks

- Could be Intrusive
- Requires considerable background knowledge and experience
- May entail additional software and hardware development

3.PSYCHOPHYSIOLOGICAL MEASURES

- Measure changes in operator Physiology
- Changes associated with different workloads have been reported in cardiac, ocular, respiratory and brain systems
- Heart rate for assessing operator state
- Endogenous eye blink rate has been shown to decrease with increased visual demand

PSYCHOPHYSIOLOGICAL MEASURES

- **Two types of brain activity have been used to study the effect of mental load**
  - **- Ongoing EEG**
  - **- Evoked Potentials**

Spectral Analysis show Decreased alpha band power with increased task difficulty

Increase in Theta band activity due to increased workload in air traffic control task

PSYCHOPHYSIOLOGICAL MEASURES

Evoked potentials are the smaller electrical brain signals that are associated with processing information.

P-300 component is found in evoked responses to task relevant stimuli and is one of the largest components that has been reported to change amplitude with mental workload demands

Physiological Measures of Workload

System	Measure
Cardiovascular system	*Heart rate
	*Heart rate variability (sinus arrhythmia)
	*Blood pressure
	Peripheral blood flow
	*Electrical changes in skin
Respiratory system	*Respiration rate
	Ventilation
	Oxygen consumption
	Carbon dioxide estimation
Nervous system	*Brain activity
	*Muscle tension
	*Pupil size
	Finger tremor
	Voice changes
	Blink rate
Biochemistry	*Catecholamines

Note: Asterisks indicate measures most commonly utilized.

(Reproduced from Meister, 1986)

Measures of Heart Rate

- Two General findings:

1. **Heart rate provides a measure of flight-segment workload i.e., take-off, landing,cruise,angle of decent to landing, etc.;**
2. **The responsibility of control of the aircraft and not just the stress of flying produces higher heart rates.**

Measures of Heart Rate

- Used as a debriefing tool during test and evaluation flights to identify unusual flight events
- Pilots are queried as to any unusual events that might have occurred on the basis of Heart-rate deviation(Roscoe and Ellis, 1990)

Measures of Heart Rate

- Heart rate measures have demonstrated the capability to distinguish workload levels associated with a variety of variables within the flight environment
- Also used as measures in non-aviation related situations(e.g., automobile drivers, cardiac patients and race car drivers)

Heart Rate Variability Measures

- Extent of normally found beat-to-beat variability decreases with increased mental workload
- Variability can be decomposed with spectral analyses techniques
- Higher levels of cognitive workload have been associated with decreased power in alpha band

Heart Rate Variability Measures

- HR variability has been used to study the effects of car driver fatigue and traffic density(Egelund, 1982)
- Unlike simple HR,HR variability was influenced by driving conditions providing additional information
- HR variability may decrease due to aging, which would invalidate its use in many people(Eckholdt et al.,1976)

Measure of Respiration

- Few studies have utilized respiration
- Studies have reported increased respiration rates while aircrew members were flying over enemy targets
- Fraser(1964) reported that the effect of High-Speed,Low-level flights increased respiration rates

Measure of Respiration

- Opmeer and Krol (1973) reported Respiration rate as a superior measure of workload to Heart rate and HR variability in simulated flight study
- Overall, Respiration rate tends to become more rapid as workload increases
- Implementation of respiration rates can be difficult

Measure of Eyeblink Activity

- Endogenous eyeblinks are those blinks which are not reflexive blinks in response to specific environmental stimuli
- Found to vary as a function of the level of visual attention to a task
- Components include Blink rate,blink duration, and blink latency relative to a stimulus or response

Measure of Eyeblink Activity

- Blink rate has a tendency to decrease under conditions of high visual workload in City Vs Highway driving(Lecret and Pottier, 1971)
- Increased blink rates have been reported for time-on-task for automobile driving(Pfaff et al.,1976) and simulated driving(Biedeman and stern, 1977)

Measure of Eyeblink Activity

- Novice helicopter pilots showed decreased blink rates over time in flight, while Experienced pilots showed no changes in blink rates during same flights (Stern and Bynum, 1970)
- Differences in data collection methods could be a factor for discrepancy in results.

Measure of Eyeblink Activity

- Significant difference in blink durations between workload levels have been reported with small mean differences, i.e.,20-30 ms
- Available evidence indicate that eyeblink activity can prove sensitive to a variety of visual information-processing demand manipulation but it is not clear if that measures will be sensitive to manipulations of auditory or cognitive task demand

Measurement Issues

- **EEG is sensitive to eye blinks, head and body movements, muscle activity and speech**
- **Do not intrude into the performance of primary task**
- **Need to present several stimuli in order to increase the Signal-to-noise ratio sufficiently**

Measurement Issues

- **User friendly equipment (Light weight, Battery powered and small psychological recorders permit the operator to go about his normal Job)**

4. ANALYTICAL MEASURES

- **Rely on Modeling of Workload Simulation**
- **Mathematical, Engineering, and Psychological models are represented in analytical workload methods**

ANALYTICAL MEASURES

- **Explicit presentation of parameters and assumptions**
- **Fosters careful consideration of the relevant input and output variables**
- **Provides specific predictions**
- **Facilitates communication of findings**

ANALYTICAL MEASURES

- **Recognize the dynamic nature of complex multitask environment**

- **Some Examples**

-TAWL (Task Analysis/Workload)

-TLAP (Time-Line analysis and Prediction)

-W/INDEX (Workload Index)

-PROCRU (Procedure Oriented Crew Model)

Measurement Issues

- Few investigation and comparisons have been performed.
- Studies indicate that three analytical methods accounted for 50% of the performance variance
- They are in particular need for validation

Measurement Issues

- In brief, because many analytical methods are recently developed, they have not been tested as much as some of the other workload metrics
- Do not require sophisticated equipment
- Can be run on common computer platforms

SUBJECTIVE Vs OBJECTIVE

- **Distinction between 'Subjective' and 'Objective' measurement is neither meaningful nor useful in human performance**
- **All measurements contain a subjective element as long as human is part of assessment**
- **No perfect measures exist**

Selecting the Type of Workload

- **Strength and Weakness need to be weighed with the specific objective of workload assessment**
- **Task/Mission/System Analysis is always necessary.**
- **An individual task can be considered sub goal in support of broader goals**

Selecting the Type of Workload

- Physiological Measures are strong in their diagnostic value
- Performance Measures could also provide diagnostic value
- Only multidimensional ratings afford diagnostic value in Subjective measures

Selecting the Type of Workload

- **Timeline analysis usefulness is limited especially in context of dynamic, Complex systems**

- **Accurate Pupil dilation(Physiological measure) can not be obtained in vibrating environment (Cockpit)**

Selecting the Type of Workload

- **Primary task performance measures and on-line subjective opinion measures can be promising**

Uses

1. Allocating functions and tasks between humans and machines based on predicted workload
2. Comparing alternative complex equipment and task design in terms of workload imposed
3. Choosing operators who have higher workload capacities for demanding tasks

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