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Relationship between Workload and Fatigue among Mexican Assembly Operators

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Abstract

Objective: To determine the levels of workload and fatigue and the relationship between these two complex constructs among Constant Velocity (CV) joints assembly operators in Mexico.

Methods: A cross-sectional and descriptive study was conducted. National Agency and Space Administration-Task Load Index (NASA-TLX) and Swedish Occupational Fatigue Inventory-Spanish (SOFI-S) version methods were applied to assess workload and fatigue, respectively. Non-parametric statistical tests were used to data comparison and correlation analysis.

Results: A total of 116 workers were recruited. NASA-TLX and SOFI-S instruments obtained high levels of internal consistency and sample adequacy. Mental Demands, Overal Effort and Physical Demands obtained the highest workload scores while Performance obtained the lowest workload score. The Overall Workload Level (OWL) showed that 47% of the workers perceived the workload as high and 52% as very high. Lack of Energy and Physical Discomfort fatigue dimensions obtained the highest scores, while Lack of Motivation fatigue dimension obtained the lowest score. Positive significant correlations were obtained between Physical Demands and Lack of Energy, Temporal Demands and Physical Discomfort, and Frustration with the six workload items.

Conclusion: Although assembly of CV joints is considered as physical task, no significant differences between Mental and Physical Demands were found. A structure equation model and a cognitive task analysis are suggested to explore the causal relationships and the components of Mental Demands.

Keywords: Workload; Fatigue; Assembly; Operators; Mental demands; Physical demands

Introduction

Due to the large number of manufacturing companies in Mexico, industrial assembly tasks are very common. According to the Mexican Agency for Statistics and Geography [1], it is estimated that approximately one million of workers perform assembly tasks in the country. Despite the large amount of assembly workers, very few studies have been developed to describe, analyze, assess, and improve the work conditions in industrial settings. Some of the latest research related to ergonomics in industrial settings are: the workload assessment and Work Related Muscle Skeletal Disorders (WRMSD) among Computer Numerical Control (CNC) lathes operators [2], the construct validity, reliability, and cutoff of the Subjective Symptoms of Fatigue Test (SSFT) [3], the development of the Fatigue-Energy Point Estimate Scale (FEPES) [4], the comparison of the WRMSD frequency between CNC lathe operators and assembly workers [5], the ergonomic evaluation of five workstations in a Mexican manufacturer of automotive parts [6], and the workload assessment in industrial settings applying the Analytic Hierarchy Process (AHP) [7].

Due to the difficulty to conduct ergonomic research in industrial settings, there are few articles published related to workload and fatigue among assembly industrial workers in Mexico. The following studies are the only two that have investigated workload and fatigue among assembly workers to date: workload as a risk factor of stress among workers of the electronic industry [8] and the comparison of factor analysis of fatigue between CNC lathes operators and assembly operators [9]. However, the levels of workload and fatigue and the relationship between these two complex constructs in this kind of industrial activity have not yet been explored.

CV Joint Assembly Task Description

In the Constant Velocity (CV) joints assembly process, the parts named "semi-axes", "bells", "tulips", and other small components are joined to create the whole piece. A typical cycle time is around 30 seconds (±5sec). The first piece used in the assembly process is the semi-axis; therefore, the weight manipulated by workers begins at 3 kg., but at the end of the sequence, the whole CV joint can weigh up to 14 kg. The workers perform three primary operations: load/unload pieces from/to the machines, component placement, and inspection. Occasionally, the workers perform another task. It is the control panel operation when a model change is needed, or a problem occurred.

In the recent years, as a result of the increasing production of cars in Mexico, the demand for automotive parts has increased too as well. Therefore, companies have increased the working hours more than eight hours per day. This situation has been reflected in worker complaints related to perception of high levels of workload and fatigue. Some studies have shown that factors like length of the workday [10], the weight manipulated [2], the cycle time [11], hours of sleep per day

[12], and others, could increase the workload and fatigue levels. The research objectives of this study were to determine the scores of workload and fatigue and to determine the relationship between the workload and fatigue among CV joints assembly operators.

Workload and Fatigue Assessment

The workload is a complex and multifaceted construct [13,14] usually defined as the portion of resource spent to develop a particular activity or task [15]. Another definition is the cost incurred by an individual, given their skills, while performing a task with specific demands [16]. According to DiDomenico [17] and Diaz [18] subjective mental workload assessment methods have shown high levels of sensitivity, demand minimal implementation requirements, are well accepted by the workers, and have obtained high levels of internal reliability. In contrast, objective methods (for example physiological and performance measures) have shown serious difficulties during data collection in industrial environments. Some of the subjective methods more used for assessing workload are the Copper-Harper Modified method (CHM) [19], the National Aeronautics and Space Administration Task Load Index (NASA-TLX) [16], the Subjective Workload Assessment Technique (SWAT) [20], the Workload Profile (WP) [21], the Multivariate Evaluation Workload (MWE) [22], the Overall Workload Level (OWL) [23], among others.

According to Kroemer [15], the term fatigue is commonly used to indicate a physiological status, but some psychologists agree that this should be used only to define a subjective experience that limits the performance of a task. However, in the same way to workload, fatigue is considered a multidimensional complex construct that differs among levels of response [24]. For example, muscle fatigue is developed when the speed and level of muscle demands in the individual exceed the physiological ability of your muscles to recover from those demands. As mentioned Jaber and Neumann, fatigue increases linearly with time. Rest periods allow physiological recovery of a worker through the overcoming of fatigue [25]. Fatigue can also be seen from a multi-factorial origin affected by circumstances not related to the job and personal characteristics, or extended character that can affect performance and the ability to function at work [26]. The fatigue is a grave threat to the quality of life and performance at work. Unfortunately, its complex dynamic nature makes it difficult to define, observe, and measure [27].

Fatigue is usually classified as acute or chronic. Acute fatigue is due to physical exertion or loss of sleep and relieved by a period of rest or sleep. Chronic fatigue is due to illness, either medical or psychological, and is not relieved by a single period of rest or sleep. The fatigue is accumulated through periods of work when there is no sufficient recovery (lack of sleep). Some of the symptoms of extreme fatigue are: blurred vision, paleness of the skin, difficulty in speech, slow response/reaction time, low body temperature, decreased heart rate, headaches and intermittent loss of muscle strength [28]. Work-related fatigue is a common complaint located in the workplace. The prevalence reported vary from <10% to >40%. There is a growing recognition that fatigue is a risk factor for accidents at work and illnesses [29], [26]. Some of the subjective methods more used for assess work-related fatigue are the Test Subjective Symptoms of Fatigue (TSSF) [30], the CR-10 (Category Ratio) [31], the Swedish occupational Fatigue Inventory (SOFI) [32], the Fatigue Assessment Scale (FAS) [33], and the Occupational Fatigue Recovery Exhaustion (OFER) scale [34].

Methods

Study design

The study design was cross-sectional and descriptive. The information was obtained through a survey applied in the workplace.

Participants

A convenience sample of CNC lathes operators was chosen considering the following

Criteria:

- • Work as an assembly operator
- • Have at least six months old at the current position
- • No history of musculoskeletal injuries the past six months
- • No cardiac or respiratory problems in the last year

Survey Administration

Survey was applied among workers of the assembly process of a manufacturer of Constant Velocity (CV) joint located in Central Mexico. After obtaining authorization to conduct the study, the overall project goals and objectives of the survey were explained to the supervisors and workers. The participants signed a consent form where they were informed about the confidentiality of the information and the use for research purposes only. After this, the survey was delivered. When the survey was answered, a small gift was given to the workers.

Measures

As a strategy for survey construction, instruments previously developed and validated showing high levels of internal consistency were selected.

National Agency for Space Administration Task Load Index method (NASA-TLX) [16] was selected for workload assessment. NASA-TLX considers six items: Mental Demands, Physical Demands, Temporal Demands, Overall Effort, Performance, and Frustration. The first three items are related to the tasks demands imposed on the worker, while the other three items related to the human task interaction. The Overall Workload Level (OWL) was calculated based on the sum of the values of the six items. According to the classification made by Generalitat of Valenciana [35], OWL is classified into four levels according to the percentage of the final score (Table 1). NASA-TLX method has been applied in numerous industrial ergonomic research around the world [7,23,36-44].

Workload level	OWL precentage	Acction
Low	1-25%	No action
Medium	26-50%	Actions recommended
High	51-75%	Actions priority
Very high	76-100%	Actions immediate

Table 1: Overal Workload Index classification [35].

Swedish Occupational Fatigue Inventory Spanish version (SOFI-S) [24] was selected for fatigue assessment. SOFI-S includes five fatigue dimensions: Lack of Energy, Physical Effort, Physical Discomfort, Lack of Motivation, and Sleepiness. Every dimension is assessing with three items (Table 2). The Overall Fatigue Level (OFL) was calculated based on the sum of the five fatigue dimensions scores. The classification of OFL was calculated using the same approach for NASA-TLX. Additional to Castilian language, SOFI has been translated into the Chinese language [45]. SOFI has been applied in numerous ergonomic research in health care [46-50], lab experiments [51,52], and industrial settings [9,12,53,54].

Dimension	Items
Lack of energy	Worn out, Exhausted, and Drained
Physical effort	Breathing heavily, Palpitations, and Warm
Physical discomfort	Stiff joints, Numbness, and Aching
Lack of motivation	Listless, Passive, and Indifferent
Sleepiness	Sleepy, Falling asleep, and Yawning

Table 2: Dimensions and fatigue items of SOFI-S questionnaire [32].

The assessment of the items on both instruments was performed using a 5-points visual analog scale that includes two written expressions, at the left "low/bad" and at the right "high/good". Survey translation, adaptation to Mx-Spanish language, and validation of NASA-TLX and SOFI were taken from Hernandez [43].

Data analysis

To analyze internal consistency, Cronbach Alpha index was applied. Cronbach Alpha index must be greater than 0.7 to consider reliable data and conduct additional statistical analysis such as correlation analysis, factor analysis, and structural equation modeling [55], among others. To verify sample adequacy, Kayser-Meyer-Olkin (KMO) index was applied. KMO index must be greater than 0.7 to consider the sample sufficient [56]. Comparison of the items and dimensions including the questionnaires was performed with the Wilcoxon rank test. Correlation analysis was performed using Kendall Tau B non-parametric analysis. A significance level of 0.05 was used for all statistical analysis. Data were collected in Excel ® software by five university students trained to avoid losing information. Statistical analysis was performed in SPSS software v21.0®.

Results and Discussion

One hundred and sixty-six assembly operators (all of them male) participated in the study. The average age was 28 (±8.3) years old. The time range in which workers answered the survey was 10-15 min.

Internal consistency analysis

Different versions of NASA-TLX and SOFI-S instruments have shown high internal consistency indices. Results of this study showed the same tendency. Cronbach Alpha was ranged from 0.552 to 0.9, and KMO index was ranged from 0.524 to 0.864. The values obtained for all items included in the survey were 0.853 for Cronbach Alpha and 0.859 for KMO (Table 3). Despite the scores of the Physical Effort fatigue dimension was low and considered bad [55], these values are similar to other SOFI applications [24,32,43,45]. Therefore, data obtained in this study can be used to perform additional statistical procedures.

Instrument	Dimension	Cronbach alpha	KMO
SOFI-S α: 0.900, KMO: 0.764.	Lack of energy	0.839	0.697
	Physical effort	0.552	0.524
	Physical discomfort	0.776	0.633
	Lack of motivation	0.776	0.630
	Sleepiness	0.864	0.731
NASA-TLX	N/A	0.679	0.706
All data. Cronbach´s alpha: 0.853; KMO: 0.859; 21 items.			

Table 3: Cronbach's alpha and KMO results.

Workload scores

Descriptive statistics (mean, median, mode, standard deviation, minimum, and maximum) of the workload items included in the NASA-TLX method are shown in Table 4. The item with the highest score (average value) was Mental Demands with 4.02 points (out a maximum of 5). According to Wilcoxon Rank test: Mental Demands, Physical Demands, and Overall Effort were not significantly different being consistent with the comparison made by Seppälä [57]. Scores of Mental Demands, Physical Demands, Temporal Demands, Overall Effort, and Frustration of assembly workers were higher than workload scores of CNC lathes operators [2]; therefore, the workload could be considered higher when workers perform assembly tasks.

The lowest score was obtained in Performance (with 1.77 points) being significantly lower than the remaining five ($p<0.05$). In this, the workers perceived less effort to accomplish their goals [16]. According to the OWL index classification [35], 1% of the workers perceived the workload medium, 47% high, and 52% very high. It is necessary to implement changes in the workstations or the work methods. These proportions were similar to Serratos´ results among CNC lathe operators where the 38.4% of CNC lathes operators perceived the workload medium and 61.6% high [2].

Variable	Descriptive data					
	Mean	Median	Mode	Std. Desv	Min	Max
Mental Demands	4.02	4	5	0.136	1	5
Overall Effort	3.91	4	4	0.116	2	5
Physical Demands	3.82	4	3	0.120	2	5
Temporal Demands	3.38	3	3	0.110	1	5
Frustration	2.94	3	3	0.124	1	5
Performance	1.77	2	2	0.740	1	4

Table 4: Descriptive statistics of the workload items.

Fatigue scores

Descriptive statistics (mean, median, mode, standard deviation, minimum, and maximum) of the fatigue dimensions included in the SOFI-S questionnaire are shown in Table 5. The highest score was obtained for Lack of Energy dimension with 8.39 points (out of a maximum of 15). According to Wilcoxon Rank test, Lack of Energy was significantly higher than the other four fatigue dimensions (p<0.05). No significant differences were found among Physical Discomfort, Physical Effort, and Sleepiness. The dimension less scored was Lack of Motivation with 5.83 points being significantly lower than the four remaining dimensions.

Results of this study showed remarkable differences against the workload assessment among CNC lathes operators [43], which the scores of the six fatigue dimensions were lower than the scores of the assembly operators. The main factor to explain this difference is the weight of the piece manipulated, ranged from 2 to 5 for CNC lathe operators [9] and ranged from 5 to 14 for assembly operators. According to the OFL classification [35], 14% of the workers perceived the fatigue as low, 80% as medium, and 6% as high. There were not results for very high level of fatigue.

SOFI-S	Mean	Median	Mode	SD	Min	Max
Lack of energy	8.39	8	9	1.05	3	15
Physical discomfort	7.11	7	5	1.10	3	15
Physical effort	6.92	6	6	0.98	3	15
Sleepiness	6.47	6	6	1.01	3	15
Lack of motivación	5.83	5	4	1.20	3	15

Table 5: Descriptive statistics of dimensions and states of fatigue.

Correlations between workload and fatigue dimensions

Correlation analysis was developed using Tau B Kendall nonparametric analysis. Table 5 shows the correlation coefficients and confidence intervals between workload items and fatigue dimensions. Physical Demands obtained a significant positive correlation with Lack of Energy and the OFL. As mentioned above, the weight of the CV joint could be up to 14 kg.; therefore, manipulated weight was a factor that contributes to the Lack of Energy and OFL, leading to general feelings of diminishing strength [32]. Frustration had significant positive correlations with all fatigue dimensions and OFL. Because it expresses insecurity, irritation, or stress about the tasks performed, workers feel their effort is not recognized [16]. Mental Demands obtained positive correlations with Physical Discomfort and the OFL. In this sense, some studies have demonstrated high levels of influence of the Mental Demands with the WRMDS [8].

OWL and OFL obtained a significant positive correlation; however, the correlation coefficient was low [58]. Personal, demographic, and psychosocial variables not explored in this study could affect the perception of workload [12]. Although Physical Demands (workload) and Physical Effort (fatigue) are similar concepts, significant correlations were not found. In this case, the age of the workers (28±8 years) is the main factor to explain why the workers did not relate the Physical Demands with the Physical Effort. OWL obtained a positive correlation with Lack of Energy, Physical Discomfort, and OFL; as a result, it explained the feelings of diminishing strength [32] and the high frequency of WRMSD in this kind of industrial tasks [2,5,11]. Performance obtained a significant positive correlation with Sleepiness; therefore, this could be interpreted as the tasks performed avoid Sleepiness (Table 6).

Workload items			Fatigue dimensions					
			LE	PE	PDi	LM	SL	OFL
MD	Correlation Coefficient		0.124	-0.003	0.227*	0.105	0.143	0.132
	95% Confidence	Lower	-0.089	-0.198	0.032	-0.110	-0.066	-0.073
		Upper	0.328	0.196	0.424	0.314	0.348	0.333
PD	Correlation Coefficient		0.280**	0.137	0.157	0.073	0.050	0.203*
	95% Confidence	Lower	0.098	-0.075	-0.044	-0.120	-0.135	0.023
		Upper	0.440	0.346	0.345	0.247	0.246	0.365
TD	Correlation Coefficient		0.186	0.150	0.249*	0.079	0.056	0.166
	95% Confidence	Lower	-0.024	-0.055	0.082	-0.133	-0.143	-0.007
		Upper	0.375	0.346	0.345	0.296	0.271	0.337
OE	Correlation Coefficient		0.164	0.173	0.095	0.000	0.127	0.125
	95% Confidence	Lower	-0.014	-0.034	-0.105	-0.233	-0.096	-0.086
		Upper	0.331	0.374	0.312	0.199	0.320	0.311
Pe	Correlation Coefficient		-0.082	0.075	0.019	0.033	0.232	0.100
	95% Confidence	Lower	-0.284	-0.127	-0.200	-0.145	0.056	-0.094
		Upper	0.125	0.267	0.218	0.219	0.409	0.292

Fr	Correlation Coefficient		0.198*	0.320**	0.267**	0.232*	0.195*	0.293**
	95% Confidence	Lower	-0.013	0.126	0.072	0.045	0.010	0.121
		Upper	0.381	0.488	0.442	0.402	0.363	0.452
OWL	Correlation Coefficient		0.267**	0.169	0.257**	0.122	0.177	0.233**
	95% Confidence	Lower	0.073	0.005	0.074	-0.081	-0.086	0.066
		Upper	0.463	0.351	0.431	0.329	0.324	0.390

MD: Mental Demands; PD: Physical Demands; TD: Temporal Demands; OE: Overall Effort; Pe: Performance; Fr: Frustration; OWL: Overall Workload Level; LE: Lack of Energy; PE: Physical Effort; PDi: Physical Discomfort; LE: Lack of Motivation; SL: Sleepiness; OFL: Overall Fatigue Level.

*Significant correlations at 0.05, ** Significant correlations at 0.01.

Table 6: Nonparametric correlations between workload items and fatigue dimensions.

Conclusion

Although assembly of CV joints is considered as physical work, significant differences between Mental and Physical Demands were not found. Statistical significant positive correlations were evident between Physical Demands, Lack of Energy, and OFL due to the weight of the piece manipulated by the workers. Workload items considered as cognitive (Mental Demands, Temporal Demands, and Frustration) obtained a positive correlation with Physical Discomfort. In the same way, a significant positive correlation was found between Performance and Sleepiness. In this sense, it is necessary to consider that at work, the fatigue is related to the task of work that is performed and exaggerated with a demand for a particular task, which is imposed on a person. The fatigue is a gradual and cumulative process, and it can be divided into the mental and physical aspects. Mental fatigue is accompanied by a feeling of weariness, reduction of the state of alert, and reduced mental performance while physical fatigue is accompanied by the reduction of performance in the muscular system.

This research contributes to a better understanding of assembly work; however, future research is needed to explore the causal relationships between workload and fatigue considering personal, demographic, psychosocial, and performance variables. A Structural Equation Modeling (SEM) and a study of states of fatigue could explain if the workers present symptoms of acute or chronic fatigue. Due to the high levels of mental workload among assembly workers, a Cognitive Task Analysis (CTA) is recommended.

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