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Construction of a survey to assess workload and fatigue among AMT operators in Mexico

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Abstract

Operators of machinery classified as Advanced Manufacturing Technology (AMT) are exposed to high levels of workload and fatigue. However, only few studies have been conducted on this topic in Hispanic-American countries workers. Several instruments be used to assess workload and fatigue; however, only few of them have been adapted to Spanish language. This paper reports on the development and validity testing of a survey instrument in Spanish, aiming to subjectively assess workload and fatigue among AMT operators in Mexico. Method: After an exhaustive literature review in search of already available measurement instruments, they were adapted for content and later translated into Spanish; a pilot test was conducted to evaluate validity and reliability; afterwards appropriate modifications were made to the testing instruments. Final version of the instrument was applied to a group of 121 operators of CNC lathes. Reliability was analyzed using KMO and Cronbach alpha indices. Results: For the assessment of workload, both NASA-TLX and ISTAS 21 methods were incorporated to the survey instrument. As for fatigue assessment tools, these were SOFI-S, FAS and OFER questionnaires. Results show KMO value and Cronbach alpha above 0.6. Conclusions. The survey instrument as designed, allows the collection of reliable and valid data regarding workload and fatigue among AMT operators in Mexico.

Keywords

fatigue; workload; assessment; reliability; AMT

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1. Introduction

1.1. Workload

The workload is a construct intrinsically complex and multifaceted [9] usually defined as the portion of resources spent to performing a particular activity, for example, the maximum capacity of performance [24]. Another definition is the cost incurred by an individual given their skills while performing a particular level of performance on a task with specific demands [33].

Methods for assessing subjective mental workload have shown high sensitivity, minimum implementation requirements, very good acceptance by workers, and adequate levels of validity in contrast, physiological indices and measures of job performance, have shown serious difficulties to be measured in the workplace [2, 1].

Some of the most widely used subjective methods for assessing mental workload are: Laboratory of Labour Economics and Sociology (LEST) [9], Modified Copper-Harper (CHM) [40], Overall Workload Scale (OWS) [25], National Aeronautics and Space Administration Task Load Index (NASA-TLX) [33], Subjective Workload Assessment Technique (SWAT) [11], Multivariate Workload Evaluation (MWE) [34], Overall Workload Level (OWL) [15], Institute of Work, Environment and Health (ISTAS 21) [35] Subjective Mental Workload Scale (SCAM) [12].

Methods mentioned above, there are only Spanish language versions of the LEST, Copper-Harper Modified, NASA-TLX and SCAM. In the case of Latin America and specifically in Mexico, the literature review did not reveal any previously used or developed method for subjective assessment of mental workload

1.2. Fatigue

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 further limits the performance of a task [23].

Some of the most widely used subjective methods for assessing work-related fatigue are: Fatigue-Related Symptoms Questionnaire (F-RSQ) [16], Borg Scale [10], Swedish Occupational Fatigue Inventory (SOFI) [5], Fatigue Assessment Scale (FAS) [14], Occupational Fatigue Exhaustion Recovery (OFER) [28], the Spanish version of the SOFI (SOFI-S)[18], Occupational Fatigue Exhaustion Recovery (OFER) [28], Fatigue Scale Energy Point Estimates (FEPES) [2], and the SOFI Spanish Modify (SOFI-SM) [4].

As for the workload in the Latin American countries have not developed assessment tools adapted by fatigue per se for this purpose. Only two relevant reports were identified in Mexico, first one is about the development of FEPES, and second is the validation of the cutoff point for the FRSQ among Mexican workers.

1.3. AMT environment

Jobs where the individual performs physical and mental effort simultaneously, the worker may present symptoms of fatigue [29, 8]. TMA operators perform this kind of work, especially where they perform loading and unloading of parts, and programming of Computer Numerical Control (CNC) machines. Physical component requires manual handling of parts with weights from 0.5 kg to 12 kg, while mental component requires programming, adjustment and exchange of die in the machines. Because of this, TMA related workers might be exposed to high levels of fatigue (Mital, 1995).

Cases where has been assessed workload or fatigue in the workplace have been developed[33, 6, 13, 27]. Other studies have been conducted analyzing the work of nurses [18, 23], and others in laboratory setting with student volunteers [26, 1]. Only in few cases workload and/or fatigue have been assessed in industrial environments that include some type of AMT.

1.4. Aims

Due to the lack of validated instruments for assessing mental workload and fatigue (physical and mental) on Mexican workers, this paper proposes to adapt and validate into Spanish language, a survey to assess workload and fatigue in industrial environments with AMT.

2. Method

2.1. Identification of questionnaires and scales

In order to identify questionnaires and scales to assess workload and fatigue were consulted scientific databases, magazines, and specialized reference books. The criteria for selecting the tools were:

- Validated in Spanish and/or other languages.
- Show content and construct validity.
- Show acceptable indices of reliability in previous research.

2.1.1. Workload assessment—According to the above criteria, two scales were selected to assess workload.

National Aeronautics and Space Administration Task Load Index (NASA-TLX) [32] is a scale multi-dimensional with six subscales: *mental demands*, *physical demands*, *temporary demands*, *effort*, *performance and frustration*. This scale is applied in two phases. In first one, participants evaluated using a paired comparison, the relative contribution of each of the subscales presented; the second phase consists in evaluating the subscales. The values obtained are used to obtain the total workload. After performing the necessary calculations, a 0-100 scale value is obtained, which is divided into 4 intervals. 0-25 (no shares), 26-50 (recommended shares), 51-75 (priority actions) and 76-100 (immediate action). NASA-TLX method has shown acceptable reliability indices and is easier to use than the Subjective Workload Assessment Technique (SWAT) [11]. Validity and usability of NASA-TLX have made this instrument is the most widely used for assessment of mental workload [31, 37].

The questionnaire ISTAS 21 is a method for assessing the effect of psychosocial factors in the workload [34]. For the construction of this survey was used the short version that includes 38 items grouped into 6 dimensions: *psychological demands* (6 items), *active work* (10 items), *job insecurity* (4 items), *social support* (10 items), *estimate to work* (4 items) and *double presence* (4 items). This questionnaire has shown acceptable reliability indices in different work environments [17, 35].

2.1.2. Fatigue assessment—For the assessment of fatigue three questionnaires were included in the survey. The first questionnaire was the SOFI-S [18]. This is an adaptation and validation of SOFI [5] to Spanish language. This instrument was developed to assess fatigue in 5 dimensions: *lack of energy*, *physical exertion*, *physical discomfort*, *lack of motivation and sleepiness*. Each dimension includes 3 items. To calculate the values of fatigue is necessary added values obtained by the 3 items included in each dimension.

The second questionnaire was the Fatigue Assessment Scale (FAS) [13] included in this study for the assessment of total fatigue. This instrument consists of 10 items: 5 for the evaluation of *physical fatigue* and 5 for the evaluation of *mental fatigue*. Fatigue results can be obtained by dimension and globally. In both cases is necessary to add the values of items.

The third and last instrument included was the Spanish version of the questionnaire OFER-S [19], which is a translation and validation of the questionnaire OFER [28]. This version was adapted and validated for use in Mexican workers. This instrument assesses three states of fatigue: *acute fatigue*, *chronic fatigue* and *intershift recovery*. Each dimension is assessed with 3 items.

2.2. Integration of the preliminary survey

The order of the survey and the items included in each scale is shown in table 1.

2.3. Measurement scales

In order to evaluate the items included in the survey, two types of measurement scales were included. For NASA and SOFI questionnaire was included a visual analogue scale of 5 divisions that includes on the left side the terms "low / bad" and the right side "high / good". For questionnaires ISTAS 21, FAS and OFER a Likert scale of 5 points was included. Values and meaning are: 1 (never), 2 (only once), 3 (sometimes), 4 (many times) and 5 (always).

2.4. Survey administration

2.4.1. Phase 1. Pilot study—The pilot study included two groups of participants, students and industrial workers. A total 110 subjects were surveyed. The objectives of the pilot study were to calculate the indices Keiser Meyer Olkin (KMO) [30] and Cronbach alpha to test the adequacy of the sample and the reliability of the data [21] respectively. Also, know the values of workload, fatigue and the time the survey is completed by the subjects.

The implementation of the first version of the student survey was conducted within the classroom to 3 groups of students. In the case of workers, implementation of the survey was

conducted in the work place during scheduled breaks; all subjects included were employees of a company manufacturer of automotive harnesses.

2.4.2. Phase 2. Application among AMT operators.—In phase 2, the survey was administered to 121 AMT operators in a manufacturer facility. All subjects surveyed work as CNC lathes operators and currently work 12 hours shifts.

The survey was delivered to the team supervisors and they were responsible for distribution to workers. Before the workers started to answer the survey, the researchers say filling instructions to supervisors and workers. During application, the researchers monitored and supported when workers complete the survey. Data collection was conducted

2.5. Survey validation

In order to verify the adequacy of the sample, Kayser-Meyer-Olkin (KMO) index was calculated, which compares the magnitudes of the observed correlation coefficients between variables with the magnitudes of partial correlation coefficients between the variables. If the value is greater than 0.7, the sample size is enough and is possible perform a factor analysis [30].

Reliability data and internal consistency was analyzed with Cronbach's alpha index, which indicates the proportion of variance in scores on the scale that is attributable to the real score. The index value must be greater than 0.7 to consider that the data are reliable [21].

These indices were calculated in both phases of the study, however the values considered for the validation and reliability of the survey are those obtained in the second phase.

For data analysis, software SPSS v17.0 was used.

3. Results

3.1. Phase 1. Pilot study.

The mean values, standard deviation, Cronbach's alpha and KMO indices of questionnaires and dimensions are shown in Table 4. In phase 1, Cronbach's alpha values were obtained from 0.427 to 0.887. KMO index was obtained from 0.513 to 0.825. In the specific case of FAS questionnaire, the lowest values in the analysis were obtained; Cronbach's alpha of 0.179 and 0.427 for mental fatigue and physical fatigue dimensions, respectively, and 0.505 for all questionnaire data. Time to complete the survey in this phase was 15-20 min.

3.2. Phase 2. Application among AMT operators.

3.2.1. Modifications to the survey.—After the results of the pilot study, two modifications were made in the survey. The first one was to eliminate FAS scale, because the Cronbach alpha values were low [21], the second modification was to move demographics section at the end of the survey [20]. The final order is shown in Table 2.

3.2.2. Participants—In the second phase of the study, the survey was administered to 121 CNC lathe operators in a company that manufactures Constant Velocity (CV) Joints located in central Mexico. Table 3 shows demographic characteristics of the sample.

3.2.3. Workload levels—Levels of workload obtained with NASA-TLX questionnaire in the first phase of the study show no important differences. Values of 3.13 to 3.85 for all variables except the variable *physical effort* that obtained 2.12 points. In the case of AMT operators, the variable with the highest average value was *performance*, obtaining 4.23 and the lowest value was *frustration* with 2.81.

Results of questionnaire ISTAS 21 shown important similarities. In both phases of the study the dimension *social support and leadership* obtained the highest score, 35.5 and 35.41 for phase 1 and phase 2, respectively. Dimensions *job insecurity* and *double presence* obtained the lowest values, in first phase obtained 11.2 and 11.7 points, respectively; in second phase obtained 8.17 and 8.65 points, respectively.

3.2.4. Fatigue levels—Fatigue levels obtained with SOFI-S questionnaire shown important differences in both studies. In the first phase, *sleepiness* dimension obtained the highest value with 8.74. In contrast, in the second phase where AMT operators were surveyed, *lack of energy* dimension obtained the highest value with 7.76.

For the OFER questionnaire, the three dimensions considered by the instrument obtained similar values with no apparent differences in the two study phases. *Chronic fatigue* dimension obtained the highest values with 15.43 and 14.46 for the first and second phases, respectively, followed by the *intershift recovery* dimension with 12.9 and 13.13 for the first and second phases, respectively, and dimension *acute fatigue* with values of 10.35 and 10.19 for the first and second phase, respectively.

3.2.5. Reliability indices—KMO index ranged from 0.552 to 0.813 and the Cronbach alpha index were 0.558 to 0.881. All calculated values can be seen in Table 4.

4. Discussion

In the second phase of the study, Cronbach's alpha index obtained for the NASA-TLX questionnaire decreased from 0.791 to 0.801, just as the KMO index decreased from 0.583 to 0.664.

In the case of the questionnaire ISTAS 21, only for *active work* dimension indices Cronbach alpha and KMO decreased from 0.825 and 0.813 to 0.628 and 0.6, respectively.

For the SOFI-S questionnaire, the values of Cronbach's alpha indices and KMO were higher than 0.7 in both phases of the study, this confirms that the application of this method for fatigue assessment is reliable. However, *physical effort* dimension obtained values lower than 0.6, the lowest values in this questionnaire. This situation coincides with the values obtained in the developing of SOFI questionnaire [5] in the validation of the SOFI-S [18], and when nurses are surveyed [23].

Finally, for OFER questionnaire, two values below 0.7 were obtained, *chronic fatigue* dimension with 0.427 for Cronbach's alpha and *acute fatigue* dimension with 0.561 KMO index. The other values were higher than 0.7 or very close to it.

5. Conclusion

Although some values were below 0.7 for Cronbach alpha and KMO, indices of reliability are consistent with the values of the sample adequacy, however is necessary to increase the sample size, recalculate these values and evaluate whether it improves the survey reliability.

Values obtained for the KMO indices and Cronbach alpha improved in the second phase of the study, with the exception of the *active work* dimension of the questionnaire ISTAS 21, *lack of motivation* dimension of SOFI-S questionnaire, and the overall value of the questionnaire NASA-TLX where rates declined. After the methodology and data analysis conducted, has been validated the first version of the survey for the assessment of workload and fatigue in AMT operators in Mexico.

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Table 1.

Survey preliminary order

Questionnaire	Items
Demographic data	14
NASA-TLX	21
ISTAS 21	38
FAS	10
SOFI	15
OFER	15
Discomfort map [7]	

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Table 2.

Final order of the survey

Questionnaire	Items
NASA-TLX	21
ISTAS 21	38
SOFI	15
OFER	15
Mapa de Corlet-Bishop [7]	
Demographic data	14

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Table 3.

Demographic data of AMT operators

Variable	n	%	Variable	n	%
Age			Time in the company		
<20	2	2	<1	13	11
21-30	77	71	1-3	32	28
31-40	25	23	3-6	53	46
41-50	4	4	6-9	3	3
>51	1	1	>20	15	13
Height (cm)			Time		
<160	5	4	<1	24	24
160-165	36	32	1-3	30	30
166-170	33	28	3-6	40	40
171-175	20	17	6-9	1	1
176-180	14	12	>20	4	4
>180	8	7			
			Position		
Weight (Kg)			Operator	116	95
<60	11	9	Grupolider/operator	6	5
61-70	31	26			
71-80	37	31	Marital status		
81-90	23	19	Single	29	27
91-100	13	11	Married	78	73
>100	3	3	Divorsed o separated	0	0
Number of dependents			Hours of sleep per night		
0	14	13	<5	3	3
1-2	55	49	5-6	37	33
3-4	36	32	6-7	39	35
>5	7	6	7-8	24	22
			8-9	6	5
			>9	2	2
Highest educational degree					
Elementary	0	0			
Secondary	9	7.6			
Preparatory	43	36.7			
Technical	65	55.5			

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Table 4.

Mean, Std. deviation, KMO and Cronbach alpha obtained in two phases .

Phase 1. Pilot study (n=110)		Phase 2. Administration among AMT operators (n=121)								
Questionnaire	Dimension	Mean	Dev Std.	KMO	Alpha	Questionnaire	Mean	Dev Std.	KMO	Alpha
NASA-TLX α: 0.791, KMO: 0.801	Mental demands	3.71	0.949	N/A	N/A	NASA-TLX α: 0.583, KMO: 0.664	3.61	0.86	N/A	N/A
	Physical demands	2.12	1.07	N/A	N/A		3.57	1.03	N/A	N/A
	Temporal demands	3.34	0.94	N/A	N/A		3.26	0.81	N/A	N/A
	Effort	3.75	0.85	N/A	N/A		3.88	0.77	N/A	N/A
	Performance	3.85	0.86	N/A	N/A		4.23	0.68	N/A	N/A
ISTAS α: 0.860, KMO: 0.712.	Frustration	3.13	1.16	N/A	N/A	2.81	1.00	N/A	N/A	
	Psychological demands	16.9	3.48	0.728	0.733	15.33	3.69	0.711	0.654	
	Active work	35	6.55	0.825	0.813	32.8	4.71	0.628	0.6	
	Job insecurity	11.2	4.09	0.548	0.521	8.17	3.56	0.681	0.641	
	Social support	35.5	6.09	0.738	0.759	35.41	6.38	0.755	0.8	
SOFIS α: 0.845, KMO: 0.756.	Estimate to work	13.16	2.93	0.760	0.764	11.82	3.65	0.768	0.846	
	Double presence	11.7	3.24	0.564	0.485	8.65	2.54	0.601	0.591	
	Lack of energy	6.54	2.56	0.728	0.836	7.76	2.29	0.700	0.827	
	Physical exertion	6.59	2.73	0.513	0.433	6.61	2.00	0.552	0.558	
	Physical discomfort	6.18	3	0.625	0.773	6.18	2.24	0.652	0.742	
FAS α: 0.505 KMO:0.746	Lack of motivation	6.28	2.31	0.731	0.887	1.99	0.72	0.619	0.754	
	Sleepiness	8.74	2.85	0.664	0.794	5.677	2.24	0.708	0.793	
	Physical fatigue	14.30	3.11	0.596	0.427	N/A	N/A	N/A	N/A	
	Mental fatigue	13.54	3.05	0.632	0.179	N/A	N/A	N/A	N/A	
	Acute fatigue	10.35	3.76	0.779	0.786	10.19	3.45	0.768	0.677	
OFFER α: 0.,724 KMO: 0.813.	Chronic fatigue	15.43	2.91	0.771	0.427	14.46	2.62	0.725	0.695	
	Intershift recovery	12.9	2.52	0.561	0.700	13.13	2.15	0.689	0.751	
α: 0.842; KMO: 0.75; 84 items.		Alfa: 0.806; KMO: 0.617; 74 items.								
Time to complete the survey: 15-20 min.		Time to complete the survey: 20-15 min.								