

Assessment of mental workload and its association with work ability in control room operators

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PAROLE CHIAVE: Carico di lavoro mentale; NASA-TLX; capacità lavorativa; sala di controllo

SUMMARY

Background: Modern technology has reduced physical workload and imposed high mental workload on the control room operators in industrial settings. The present study was conducted among control room operators to assess their mental workload, investigate their workability, examine the relationship between mental workload and workability, and determine the factors associated with workability. **Methods:** This cross-sectional study was carried out among 213 control room operators in six Iranian process industries. Task Load Index (NASA-TLX) was used to assess the mental workload, and Work Ability Index (WAI) was used to determine workability. The relationships between demographic characteristics and dimensions of mental workload and workability were examined by univariate tests. Logistic regression analysis was also used to determine the factors associated with the operators' workability. **Results:** The results showed a high mental workload in the study population (82.38 ± 8.8). Yet, the operators showed a good and excellent level of workability (56.4%). Pearson's correlation coefficient revealed a significant inverse linear relationship between the mean score of mental workload and workability ($r = -0.581$). Besides, regression modeling demonstrated that mental demand (OR=0.90), temporal demand (OR=0.90), effort (OR=0.91), frustration (OR=0.92), from NASA-TLX subscales were significantly associated with workability. Moreover, mental and temporal demands were important factors associated with reduced workability. **Conclusion:** Monitoring tasks imposes high mental workload on the control room operators, which may result in adverse effects on their workability as well as on the safety of the system.

RIASSUNTO

«Valutazione del carico di lavoro mentale in associazione con la capacità lavorativa in operatori di sala di controllo». **Introduzione:** Le moderne tecnologie hanno ridotto il carico di lavoro fisico ma, parallelamente, hanno imposto un alto (o aumentato il) carico di lavoro mentale negli operatori di sala di controllo in contesti industriali. Il presente studio è stato condotto tra operatori di sala di controllo per valutare il carico di lavoro mentale e la capacità lavorativa, esaminare la relazione tra carico di lavoro mentale e capacità lavorativa, e determinare i fattori associate

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con la capacità lavorativa. **Metodi:** Uno studio trasversale è stato condotto su 213 operatori di sala di controllo in sei industrie di trasformazione iraniane. Il Task Load Index (NASA-TLX) è stato impiegato per valutare il carico di lavoro mentale, mentre il Work Ability Index (WAI) è stato usato per determinare la capacità lavorativa. Le relazioni tra caratteristiche demografiche e dimensioni di carico di lavoro mentale e capacità lavorativa sono state analizzate attraverso test univariati. L'analisi di regressione logistica è stata usata per determinare i fattori associati con la capacità lavorativa degli operatori. **Risultati:** I risultati mostrano un alto carico di lavoro mentale nella popolazione studiata (82.38 ± 8.8). Tuttavia, gli operatori hanno mostrato buoni ed eccellenti livelli di capacità lavorativa (56.4%). L'indice di correlazione di Pearson ha mostrato una significativa relazione inversamente lineare tra lo score medio del carico di lavoro mentale e la capacità lavorativa ($r = -0.581$). Inoltre, il modello di regressione ha dimostrato che esigenze mentali (OR=0.90), esigenze temporali (OR=0.90), sforzo (OR=0.91), frustrazione (OR=0.92), delle sottoscale NASA-TLX erano significativamente associate con la capacità lavorativa. Infine, le esigenze mentali e temporali erano importanti fattori associati con una ridotta capacità lavorativa. **Conclusioni:** Monitorare i compiti assegnati impone un alto carico di lavoro mentale negli operatori di sala di controllo, che può avere effetti negativi sulla loro capacità lavorativa e sulla sicurezza del Sistema.

INTRODUCTION

With the rapid advancement of technology, complex work systems have appeared in industries (25), resulting in increased mental workload (24). In many industrial settings, such as nuclear, chemical, military, and medical industries, critical systems with advanced technologies are used (11). Controlling modern complex systems often imposes heavy mental workload on operators (18), which influences their performance and safety. In other words, the operators' performance is associated with their mental workload in such a way that the best performance occurs at an acceptable level of mental workload (31, 34).

Mental workload refers to the effort made by the mind while doing tasks (43). Quick and affordable subjective self-report tools such as NASA-TLX are used for mental workload assessment in employees whose occupation requires high mental accuracy, speed of action, and controlling tasks with critical decision-making (7). Under excessive mental workload, human operators may experience delays in processing the information. Indeed, they may not be able to respond to input data because the amount of data is higher than their processing capacity, which can reduce their judgment and decision-making abilities while performing the task (34). In other words, high mental workload is ac-

companied with reduced work ability and performance (26). Some studies suggested that too high or low mental workload will result in the decline of employee's work ability (38, 46). Work ability describes an operator's capacities and capabilities with regard to physical and psychosocial demands. Work ability is a complex concept, which can be affected by individual, social, and work-environment factors (19). Strengthening the work ability is one way to increase the efficiency of human resources in industries and organizations (2). Work ability is also an important factor in identifying the workers who are at risk of imbalance among health, ability, and professional needs (42).

Employees with capabilities to meet their job requirements are less likely to err (37). In other words, if workers' physical and mental capabilities do not conform to their job requirements, safety problems, reduced production, and increased work force turnover are expected (28). This issue is of particular importance for individuals working in high technology settings, such as nuclear power plants and other process industries (37). Health and work ability are important factors in workers' occupational safety in these processing industries (10). In the control room, operators should receive and process large amounts of data in a short period of time and make decisions accordingly. It is clear that catastrophic accidents may take place where errors occur in such decision-

making situations (48). Accidents in complex systems not only cause large financial losses, but they can also be life-threatening (14). In 1994, the explosion and fire in Texaco refinery killed 24 individuals and resulted in damage equal to 48 million pounds. This is an example of such accidents, which occurred due to human error, where the control room operator had to recognize and take appropriate measures for 275 alarms 11 minutes before the explosion (45).

Many subjective procedures exist to measure the mental workload, such as Cooper-Harper Scale, Bedford Scale, Subjective Workload Assessment Technique (SWAT), and Task Load Index (NASA-TLX) (26). NASA-TLX and SWAT are largely used in many fields, such as aeronautics (8) and surgery (30). NASA-TLX is more acceptable to participants and is more sensitive to mental workload differences, particularly at low workload levels (39), but the researcher has used NASA-TLX in a study in which the participants have a high-level of mental workload (5, 6, 39).

Studies have shown that mental workload may lead to mental job stress (9), that, in turn, increases human errors (28) and reduces work force's productivity (16). The severe consequences of accidents in the above-mentioned industries and the critical role of human factors in the control room of complex industrial enterprises, which is regarded as the beating heart of the system, on the one hand, and the fact that control room operators have important roles in preventing errors and human and financial damages as well as infra-organizational threats on the other hand lead us to this point that assessment, maintenance, and improvement of the employees' work ability is of great importance in order to increase productivity and prevent the employees' early retirement.

Since no studies have been carried out so far to assess the mental workload and work ability in the control room operators in Iran, the present study was conducted among the control room operators of Iranian process industries with the following objectives:

- a) To assess mental workload,
- b) To investigate the operators' work ability,
- c) To examine the relationship between mental workload and work ability, and

- d) To determine the factors associated with the operators' work ability.

METHODS

This cross-sectional study was conducted on the control room operators of six process industries, including oil, gas, petrochemical, and power plants, in Fars, Bushehr, and Khuzestan provinces located in the south of Iran from January to June 2015. In this study, 213 male operators with at least one year of job tenure were selected through consensus. All subjects signed informed consent forms before commencement of the study. The study protocol was reviewed and approved by the Ethics Committee of Shiraz University of Medical Sciences.

Data gathering tools

The required data were collected through anonymous self-administered questionnaires. A demographic questionnaire was used to collect personal details, including age, weight, height, Body Mass Index (BMI), job tenure, daily working time, marital status, education level, type of employment, pre-employment specialized training, and working schedule.

To assess the mental workload, NASA-TLX was applied. It is a well-known self-report index developed by Hart and Staveland in 1998 (15). This index is calculated in two steps. First, the participants are asked to complete a pair-wise comparison process in order to give weight to six subscales or dimensions of mental demands, physical demands, temporal (time) demands, performance, effort, and frustration. Second, they are requested to determine a score in a 0-100 scale. The final score of the index is obtained using a formula and by combining the two steps. The face validity of NASA-TLX has been verified in previous studies (29).

In order to determine work ability, we used Work Ability Index (WAI). This index was developed by Ilmarinen at the Finnish Institute of Occupational Health (FIOH) based on a theoretical model of work ability (40). The instrument consists of seven items, each of which is assessed using one or more questions. This index is calculated using the sum of the scores obtained for each item as follows:

1. Current work ability compared to the lifetime best (0-10 points)
2. Work ability in relation to demands of the job (2-10 points)
3. Number of current diseases diagnosed by a physician (1-7 points)
4. Estimated work impairment due to diseases (1-6 points)
5. Sick leave during the past 12 months (1-5 points)
6. Personal prognosis of work ability in two years from now (1, 4, and 7 points)
7. Mental resources referring to the worker's life in general, both at work and during the leisure time (1-4 points).

The WAI score ranges from 7 to 49, with higher scores indicating better work ability. Accordingly, scores 7-27, 28-36, 37-43, and 44-49 represent poor, moderate, good, and excellent work abilities, respectively. The validity and reliability of the Persian version of the questionnaire were examined by Abdolizadeh et al. in Iran (1).

The participants were provided with the questionnaires in their workplace. They were required to complete the questionnaires while performing their jobs during their work shifts in the presence of the researchers.

Data analysis

Statistical analyses were performed using the SPSS statistical software, version 19. Descriptive statistics, including mean and Standard Deviation (SD), were used to describe the variables. Using Kolmogorov-Smirnov test, we examined the normal distribution of the data. Then, t-test was used to compare the quantitative variables with two independent qualitative groups. Besides, ANOVA was used to compare the means of the quantitative variables with more than two qualitative groups. Chi-square test was also used to compare qualitative variables. Pearson's correlation test was used to examine the relationship between quantitative variables, such as mental workload and work ability scores. Indeed, logistic regression analysis was used to determine the factors associated with the operators' work ability. In this regard, variables with

$p \leq 0.25$ in univariate analysis were entered into the regression model (21). In all tests, the significance level was set at 0.05.

RESULTS

The demographic characteristics of the control room operators who participated in the study are summarized in table 1.

NASA-TLX

The results of NASA-TLX questionnaire are presented in table 2. With respect to various dimensions of NASA-TLX, the minimum and maximum scores were related to 'physical demand' and 'mental demand' dimensions, respectively. The total mean score of NASA-TLX was 82.38.

The results of ANOVA, independent sample t-test, and correlation coefficient showed that the mean score of NASA-TLX was significantly influenced by BMI ($p=0.002$), nurture of job ($p=0.011$), pre-employment specialized training ($p=0.031$), and education level ($p=0.043$).

WORK ABILITY INDEX (WAI)

The mean score of WAI was 36.82 ± 5.33 , which placed the participants in the good work ability group. The distribution of work ability levels among the operators is presented in table 3. Accordingly, 4.2% of the participants scored below 27 (poor work ability), 39.4% scored 28-36 (moderate work ability), 48.8% scored 37-44 (good work ability), and 7.5% scored 44-49 (excellent work ability). Thus, 43.6% of the studied participants were at the poor-moderate level of work ability.

The results of ANOVA indicated the influence of BMI ($p=0.003$) on WAI. The results of chi-square test also showed that WAI was significantly influenced by the type of employment ($p=0.008$) and education level ($p=0.036$). Also, there was no significant relationship between the mean age and different levels of work ability ($P=0.371$). Therefore, different age groups were not compared with the level of work ability.

Table 1 - Demographic characteristics of the operators under the study (n=213)

Age (years)	Mean (SD)	34.98 (6.81)
	Min-Max	24-59
Job tenure (years)	Mean (SD)	10.16 (6.75)
	Min-Max	1-32
Height (cm)	Mean (SD)	176.22 (6.45)
	Min-Max	154-191
Weight (kg)	Mean (SD)	80.53 (11.02)
	Min-Max	53-122
BMI (Kg/m ²)	Mean (SD)	25.9 (3)
	Min-Max	17.36-34.89
Type of employment	Formal (%)	184 (86.4)
	Contractual (%)	29 (13.6)
Marital status	Single (%)	52 (24.4)
	Married (%)	159 (76.4)
	Others (%)	2 (0.9)
Education level	Diploma (%)	22 (10.3)
	A.D. (%)	9 (4.2)
	B.Sc. (%)	182 (85.5)
Pre-employment specialized training*	Yes (%)	199 (93.4)
	No (%)	14 (6.6)
Daily working time (hrs)	8 [‡] (%)	121 (56.8)
	12 [†] (%)	92 (43.2)
Working schedule	2 weeks work - 2 weeks rest [†] (%)	64 (30)
	1 week work - 1 week rest [†] (%)	13 (6.1)
	3 weeks work - 1 week rest [†] (%)	10 (4.7)
	2 weeks work - 1 week rest [†] (%)	5 (2.3)
	3 shifts work - 4 days rest [†] (%)	78 (36.6)
	3 days work - 2 days rest [†] (%)	43 (20.2)

* Training given to the operators before starting their routine jobs in the control room

[‡] 8-hour shift

[†] 12-hour shift

The correlation between NASA-TLX and WAI scores

In order to examine the correlation between the mean scores of mental workload (NASA-TLX) and work ability (WAI), we used Pearson's correlation test. The correlation coefficient (-0.581) represented a significant negative correlation between these two indices (p=0.0001). The mean scores of mental workload (NASA-TLX) at different levels of work ability are shown in figure 1. Accordingly, an in-

crease in mental workload was accompanied with a decrease in work ability.

Factors associated with workability

To determine the factors affecting work ability using logistic regression analysis, we classified the response variables into high (excellent and good levels) and low work ability (moderate and poor) categories. According to the results of ANOVA and chi-square tests, pre-employment special-

Table 2. Mean \pm SD and min-max scores of NASA-TLX dimensions among the operators (n=213)

Workload dimensions	Mean	SD	Min	Max
Mental demand	92.25	11.03	35	100
Physical demand	36.15	19.69	0	90
Temporal demand	86.45	13.31	25	100
Performance	80.68	12.88	30	100
Frustration	86.13	13.75	30	100
Effort	59.30	25.64	0	100
Total workload	82.38	8.89	49.66	100

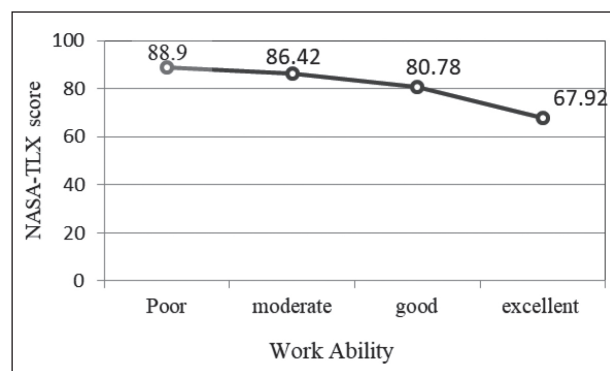
Table 3. Distribution of the operators in different categories of work ability (n=213)

Levels of work ability	N (%)
Poor (7-27)	9 (4.2)
Moderate (28-36)	84 (39.4)
Good (37-43)	104 (48.8)
Excellent (44-49)	16 (7.6)

ized training, education level, marital status, type of employment, BMI, and daily working hours as well as mental demand, physical demand, temporal demand, effort, and frustration from NASA-TLX subscales were eligible to enter the logistic regression model ($p < 0.25$). After adjusting for the potential confounding factors, logistic regression modeling showed that mental demand, temporal demand, effort, and frustration were significantly associated with work ability ($p < 0.05$) (table 4).

DISCUSSION

The mean score of NASA-TLX indicated that the control room operators' mental workload was higher compared to those reported in other studies conducted on other job groups (7, 27, 35). The

**Figure 1** - Mean scores of mental workload in different categories of work ability

reason could be attributed to the nature of the job, sensitivity of the tasks, and the utilized equipment and systems (22). In the present study setting, the physical workload was low, while the mental workload was high.

The mean score of WAI was classified as 'good' ($WAI > 36$), which is in line with the results of other studies conducted in Iranian petrochemical industry and Croatian oil industry (3, 10, 28). Although the mean score of WAI was at the good level, 43.6% of the participants were at the poor-moderate level.

The study results supported the hypothesis that mental workload adversely affected work ability, in such a way that increase in mental workload was associated with reduced work ability. Xiao et al. showed that when mental workload was high, work ability was negatively correlated to mental workload (46). Safari et al. also showed in their study that low mental workload at work was directly related to higher work ability (36). This indicates the necessity to match the individuals' capabilities with their job requirements (26).

Based on the results of logistic regression analysis, mental demand, temporal demand, effort, and frustration had the strongest influence on the op-

Table 4. Models indicating the factors affecting the operators' work ability (n=213)

Dimensions	OR (CI _{0.95})	B (SE)	Wald	P-value
Mental demand	0.896 (0.84-0.95)	-0.11 (0.032)	11.73	0.001
Temporal demand	0.899 (0.84-0.95)	-0.16 (0.031)	11.21	0.001
Effort	0.913 (0.86-0.96)	-0.091 (0.029)	9.98	0.002
Frustration	0.917 (0.87-0.96)	-0.087 (0/027)	10.77	0.001

erators' work ability. The results also showed a significant relationship between mental demand and work ability. An inverse relationship was also found between mental demand and work ability, which is in line with the results of other studies (33, 38, 40, 41). Because of the individuals' limited capacity of attention resources, as job demands begin to exceed their capacity limits, skilled operators tend to use compensatory strategies to adjust themselves to the required job demands (6). Studies have shown that when job demands exceeded the subjects' capabilities, a decrease was observed in their judgment and decision-making abilities, which could eventually result in the loss of work ability.

The current study findings revealed a significant negative association between temporal demand and work ability. This finding is in agreement with that of the study by Heansen *et al.*, which demonstrated that time pressure was effective in work ability (13). Other studies have also shown time pressure as one of the factors that could predict work ability (18). These results were also in line with those of the research by Ilmarinen, which revealed low work ability in the subjects who worked under time pressure (20). Time pressure has been proved to be one of the most common stressors in the work environment, which leads to highly emotional reactions. More specifically, individuals' experiences would raise anxiety, causing more attention resources to be allocated to the task, thereby increasing the cognitive load (8).

The present study results showed a significant negative correlation between the 'effort' dimension in NASA-TLX and work ability. Effort means that a person has to work hard to accomplish one's level of performance (15). Since the nature of the control room operators' job was mental (rather than physical), the majority of the participants focused on the mental effort required to achieve proper performance. High mental workload is associated with high mental effort (17). When job demands increase, effort has to be mobilized in order to maintain the performance levels, which is associated with physiological and psychological costs (12).

The current study findings demonstrated a significant inverse relationship between frustration and work ability. Frustration refers to stress, anxiety, and

discourage while doing a task (39). A study showed that frustration was most directly linked to constant heavy workloads (44). It should be noted that most of the study participants paid particular attention to stress and anxiety aspects of frustration, which is in agreement with the studies carried out by Kumasiro in oil industry (23) and by Habibi *et al.* (10) in petrochemical industry. Research has shown that stress-related symptoms could be predicting factors in assessing the individuals' work ability (32).

Limitations

This study had some limitations. Firstly, the cross-sectional design of the study did not allow actual causative conclusions to be made. Secondly, use of self-report measures could result in deception, denial, or recall biases. Finally, mental workload was measured using subjective methods, while the use of objective measures could lead to more conclusive results.

CONCLUSIONS

The findings of the present study indicated that mental workload was high and work ability was good in the control room operators. Indeed, increment in mental workload was associated with decrement in work ability. Moreover, mental demand, temporal demand, effort, and frustration were recognized to influence work ability. Thus, identifying and optimizing the factors affecting mental workload and work ability in control room operators should be considered in priority in any interventional program.

NO POTENTIAL CONFLICT OF INTEREST RELEVANT TO THIS ARTICLE WAS REPORTED BY THE AUTHORS

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