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Mental Fatigue Assessment Method Based on Assembly Operation

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Abstract. In this study, NASA-TLX (National Aeronautics and Space Administration-Task Load Index) scale was used to evaluate subjects' fatigue before and after digital cognitive tasks, and the performance of operators' assembly operation was adopted as the criterion so as to study the validity and applicability of NASA-TLX scale. The results suggested that NASA-TLX scale showed a good reliability and validity when it was used to evaluate subjects' mental fatigue induced by digital cognitive tasks. There was a significant correlation between NASA-TLX scale and the performance of assembly tasks, which indicated that NASA-TLX scale had a good predictive effect on operators' performance to a certain extent. NASA-TLX can serve as an ideal tool for mental fatigue measurement in assembly work.

1. Introduction

With the automation and intelligence of modern manufacturing systems, the operation of some large machines and CNC machine tools requires more and more cognition resources. Long-time work will lead to an increase in mental workload and fatigue[1], which will affect the productivity of the operator and the safety of the production system[2]. Therefore, the effective assessment of mental workload not only helps to improve the working efficiency of workers, but also reduces the safety accident rate at the production site and promotes safe and efficient production.

At present, the measurement and evaluation methods of mental workload mainly include physiological measurement, performance measurement and subjective measurement method. The physiological indicators involves heart rate, eye movement, Electroencephalogram(EEG), and muscle activity[3,4]. Physiological measurement method has attracted wide attention due to its objectivity and real-time properties. However, it requires high hardware and environment, and improper wearing will interfere with the experimental state of the subject. Generally, the error rate and reaction time of the operator in completing the task is used to evaluate the operating performance[5]. However, in performance revaluation, the task performance difference may not necessarily reflect how much cognition resources and energy the operator spends. Previous research tends to combine performance index assessment with subjective assessment or physiological measurement methods to evaluate the mental workload of operators, and found that there was consistency in the assessment results of subjective scales, performance indicators, and physiological measurement methods[6]. As for subjective measurement method, scholars has designed and developed a variety of subjective scales, such as the SWAT (Subject Workload Assessment Technique) scale, PAAS scale, WP (Workload Profile) scale, OW (Overall Workload) scale and NASA-TLX (Task Load Index) scale, etc. [7]. In view of the possible differences in the mental and physiological loads involved in tasks with different characteristics, whether subjective measures are applicable to different types of cognitive operations still requires research on the validity and applicability of the scale.

Based on the literatures above, it can be found that the existing mental workload research focuses on the fields of aviation, driving, health care and human-computer interaction[8]. However, there are few literature on mental workload assessment of operators in manufacturing field. Considering the limitations of the current research on workers' mental fatigue in the production field, this paper designed an experiment based on LEGO simulation manual assembly, using the performance change of the operator on the assembly task before and after the digital cognitive operation as the benchmark. Reliability and validity evaluation of the scale index is intended to provide a reference for the evaluation and selection of subjective measurement methods of mental workload for similar tasks in assembly operations and production.

2. Methods

2.1 Participants

Twenty-four undergraduate and postgraduate students (12 males and 12 females), aged 22-28 years old, are all right-handed and have normal vision.

2.2 Experimental Tasks

The experimental task consisted of two parts. The first part adopted manually assembly tasks with the LEGO model. Actions during assembly task involved finding, selecting, positioning, grasping, moving, and positioning. This kind of task can represent the assembly tasks of some precision instruments[9]. Studies suggested that this type of task required more cognitive demand for participants and is sensitive to individual fatigue. The second part uses a simple number task. The task process includes selecting the odd number from two columns of selected numbers and transcribing it to the specified position.

2.3 Experimental Procedures

Before the experiment, the participants were introduced about the entire process and precautions of the experiment. Then, the subjects performed 2 Lego model assembly tasks; 4 digital tasks; and 2 model assembly tasks again. After the experiment, participants completed the NASA-TLX scale.

3. Data Analysis and Results

3.1 Analysis of Performance Indicators

The Paired Sample T Test was used to analyze the performance data of the two model assembly tasks before and after the digital tasks to analyze whether the digital cognitive tasks would cause performance changes. The results are shown in the Table 1. The results showed that the difference of accuracy rate was statistically significant, t=2.852, P<0.001. Before and after the digital cognitive task, the task completion time increased significantly, t = -9.658, P <0.001.

Table 1 t-test of two assembly task performance

	Assembly task		t	95% Confidence Interval	
	Before	After		Lower	Upper
Accuracy rate	0.999 (0.005)	0.986 (0.035)	2.852*	0.004	0.023
Task completion time[s]	489.550 (135.556)	503.104 (135.766)	-9.658*	-16.457	-10.651

3.2 Reliability of the NASA-TLX Scale

The correlation between the six-dimensional load of the NASA-TLX scale and the total workload was analyzed based on the experimental data. The results of the SPSS analysis were shown in Table 2. The six dimensions of the NASA-TLX scale (mental demand, physical demand, time demand, performance, effort, and frustrations) resulted in a Cronbach'α coefficient of 0.712, which suggested that its inherent consistency reliability was excellent. This result indicated that NASA-TLX scale showed good reliability to assess the degree of mental workload.

Table 2 Correlation analysis of each dimension of the scale and total workload

	Physical	Time	Effort	Performance	Frustration	Total

	demand	demand				workload
Mental demand	0.676*	0.000	0.554	0.192	0.095	0.690*
Physical demand		0.369	0.515	0.350	0.378	0.777*
Time demand			0.115	0.527	0.354	0.589
Effort				-0.223	0.167	0.735*
Performance					0.385	0.393
Frustration						0.290

3.3 Structural Validity of the NASA-TLX Scale

Factor analysis method was used to evaluate the structural validity of NASA-TLX scale data in all dimensions. After orthogonal rotation, the corresponding common factors (eigenvalues≥1) were extracted to obtain two factors. The cumulative contribution rate was 69.970% (see Table 3). Mental demand, physical demand, time demand, and effort had a larger factor load on the first factor (0.635 ~ 0.874), and frustration had a greater load on the second factor (0.684). Mental, physical and time demand can reflect the fatigue level of the operator during the task, which was consistent with previous research[10].

Table 3 Factor analysis of NASA-TLX scale

	Factor load		Communalities
	1	2	
Mental demand	0.874		0.795
Physical demand	0.722	-0.523	0.790
Time demand	0.649	0.381	0.557
Effort	0.635	0.392	0.735
Performance	0.485	-0.707	0.756
Frustration	0.537	0.684	0.566
Eigenvalues	2.127	2.071	
% of Variance	43.872	26.098	
Cumulative %	43.872	69.970	

3.4 Analysis of Fatigue and Performance Changes

Correlation analysis was performed on the performance indicators changes of the two assembly task before and after the digital cognitive task and the evaluation results of the NASA-TLX scale, as shown in Table 4. The results showed that the accuracy rate of assembly tasks was significantly negatively correlated with performance level ($r = -0.626$, $P<0.05$) and frustration ($r = -0.627$, $P <-0.05$), and was significantly positively correlated with mental demand ($r = 0.251$, $P <0.05$). Task completion time was significantly positively correlated with mental demand ($r= 0.128$, $P <0.05$), but was significantly negatively correlated with effort ($r = -0.176$, $P <0.05$). The results showed that fatigue increased after subjects completed digital cognitive tasks, leading to a downward trend in their performance on continuous attention tasks.

Table 4 Correlation analysis of assembly task performance change and NASA-TLX scale

	Accuracy rate	Task completion time
Mental demand	0.251*	0.128*
Physical demand	-0.071	-0.139
Time demand	-0.005	0.171
Effort	0.105	-0.176*
Performance	-0.626*	-0.137
Frustration	-0.627*	0.129
Total workload	-0.117	-0.031

4. Conclusion

The results suggested that NASA-TLX scale, as a measurement of mental fatigue in assembly process, showed a good level of reliability and validity. NASA-TLX scale can be used to evaluate the mental workload during manual assembly task in manufacturing field. This study revealed that the mental demand and performance level in NASA-TLX scale were more sensitive to the fatigue induced by digital cognitive operation. The results showed that long-term digital testing may lead to subjective fatigue and affect the operators' performance in manual assembly tasks. With the change of the application environment of NASA-TLX scale, the weight of each dimension of the scale will change accordingly.

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