Performance Study of Light Assembly Operations Considering Time Pressure and Task Complexity

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Abstract. Performing tasks of different complexity under different time pressures has different effects on the operator's operational performance. In this paper, the Lego model is used to simulate the actual light assembly production operation, and the light assembly experiment with different complexity and different time pressure is designed. The operator's operational performance indicators are recorded to analyze the impact of task complexity and time pressure on the operational performance of light assembly operators. The results show that the task complexity leads to significant differences in the operator's operational performance. Time pressure does not lead to significant differences in the operator's operational performance. There is an interaction between the two; there are significant differences between the four types of assembly task completion error rates.

Introduction

With the increasing competition in the market and the rapid change of customer demand, in the manufacturing operations dominated by assembly operations, multi-variety and small-batch mixed-flow production helps manufacturing enterprises to effectively achieve rapid response to the market, reduce production costs, and reduce the inventory of work-in-progress etc. It is a high-efficiency, high-quality, flexible production method, which has become the mainstream production method of today's advanced manufacturing enterprises. Multi-variety and small batches increase the complexity of the assembly line. In industrial assembly and assembly production, a large number of products are assembled from the assembly system by assembling various components, and these assembly operations are completed by the first-line assembly staff. Although with the introduction of robots, the traditional assembly line turned to the automatic assembly line, freeing employees from the monotonous, often tight, high-tempo work sequence assembly line. However, there are still many complicated assembly operations, and manual assembly is the most effective solution. With the individualization and complication of products, assembly operations are becoming more and more complex, and manual assembly will still exist in a short period of time. Manual assembly has a higher performance due to its high flexibility.

The intensification of competition in the business environment makes it necessary to complete a large number of tasks in a limited time to become the norm for most employees. Time pressure is a typical work requirement, which consumes the physiological, cognitive and emotional resources of employees, and have a negative impact on job performance. A large number of scholars have studied the relationship between time pressure and performance. Liu D et al. studied the effects of time pressure and target uncertainty on the performance and workload of autonomous UAV operators, and found that time pressure has a significant impact on subjective workload levels and secondary task performance scores. Wang L et al. studied the quantitative relationship model between workload and time pressure under different flight operations tasks. Three different tasks were set under different time pressures, and the three workload measurement parameters and the subjective sensory threshold of time pressure were measured experimentally. The results show that there is a significant difference in workload at different time pressures. Everaert P et al. studied the cost targets and time pressures of the new product development process. Under high time pressure, the cost goal caused
the design engineers to work longer in design without corresponding cost reduction. Buckert et al. believe that time pressure can increase individual risk by increasing physical stress and increasing adventure of risk.

In the past, the research from the two dimensions of task complexity and time pressure was mainly in the marketing, economics, aviation and other industries. In the light assembly operation based on action skills, there are also problems caused by time pressure, reasonable assessment of the impact of time pressure and task complexity on light assembly operations can guide companies to scientifically develop response measures. In recent years, in the process of scientifically configuring production systems to improve production efficiency, industrial engineers have realized that the “human standard” has gradually become a bottleneck restricting further optimization of production management. The optimization of production management needs to comprehensively consider the human body state and production status information, pay too much attention to the design of production equipment, and ignore the changes in the state of emotion or fatigue in the production process, and the result will affect the external behavior of employees. It is not conducive to the improvement of production efficiency and the optimization of production management, which greatly affects the systematic process of industrial engineering. In the context of manual assembly, workers performing assembly tasks often face different cognitive needs, such as tools, methods, assembly orientation, component batch size, etc., and each of these factors can be relatively easy without time pressure. But when these factors are combined with the triggering of time pressure, it will have an impact on the operator's state, which will affect the operator's behavior and affect performance.

The assembly of electronic products such as mobile phones is a typical representative of light assembly. The LEGO model assembly is the same as the mobile phone assembly process, and can represent light assembly tasks based on motion skills such as electronic products and instrumentation assembly. Therefore, this paper selects the LEGO model as the experimental object, and designs the task complexity (simple; complex) × time pressure (high; low) Lego model to simulate the light assembly experiment, record the operator's operational performance, error rate indicators, analyze the impact of time pressure and task complexity on the operational performance of light assembly operators, understanding the behavior of operators in the production organization, providing a theoretical basis for the company to assign tasks, formulate reasonable production plans, and ensure product quality, so that enterprises can carry out sustainable and efficient production.

Method

Participants

According to the similar experimental paradigm and G-power sample size, 24 students (14 males and 10 females) who were not involved in any model assembly for nearly one year were randomly recruited, aged 21-24, all participants had normal or corrected visual acuity, no color blindness or physical impairment, which met the requirements of light assembly experiments. During the experiment, each participant was randomly assigned to a different experimental task.

Material

The simple task of this experiment is to assemble a 12-layer Lego model using five types of model parts. The size, color, mounting position and sequence of the required materials are shown in Figure 1(a). The complex task is to assemble a 7-layer Lego model using 13 types of model parts, and two different 7-layer Lego models need to be assembled, the three views of the model are shown in Figure 1(b). According to the objectives, operations, methods, selection rules (Goals, Operations, Methods, Selection rules, GOMS) model to calculate the number of working memory (WM) modules required for the task, to ensure that the task design meets the experimental requirements. The time pressure is calculated by the time pressure (TP) formula TP = Tr / Ta of the task operation proposed by Siegel et al., where TP represents time pressure, Tr represents the time required to perform the task, and Ta represents the available time to perform the task. Tr was measured by a pre-
experiment before the formal experiment, and then Ta was obtained from the time pressure calculation equation based on the values of Tr and TP, and the experiment time was set by Ta. Time pressure occurs when the time required to perform a task exceeds 70% of the task's available time.

Figure 1. Assembly task standard operation instruction map.

| Task type  | Description                                                                 | Number of MVs |
|------------|------------------------------------------------------------------------------|---------------|
| Simple task| Assembling a 12-layer model according to the job diagram using 5 differently shaped parts | 4             |
|            | Assemble a 7-layer model according to the job diagram using 13 differently shaped parts |               |
| Complex task | Assembling a 7-layer model according to the job diagram using 13 differently shaped parts | 7             |

**Experiment Process**

The participants were introduced to the relevant situation of the experiment and the precautions during the experiment. The participants agreed to participate in the experiment, they need to read and sign the informed consent form. After the participants were thoroughly familiar with it, a formal test was conducted. Before the formal experiment, tr was measured by pre-experiment. The low-time pressure of this experiment was set to 0.8, and the high-time pressure was set to 1.1. The experiment was divided into 4 groups. The models of the Lego assembly were consistent in each group. The complexity and time constraints of the experiment are different, with 12 simple tasks and 15 complex tasks.

**Experimental Dependent Variable**

During the experiment, the average assembly time and error rate of the completed assembly tasks were recorded. The average assembly time of the simple and complex tasks was analyzed by video recording statistical analysis to measure the impact of time pressure on the performance of the assembly task. The error rate refers to the number of layers that are different from the shape, color, direction and order in the standard specification after the participants completes the assembly task, and the ratio of the number of error layers to the total number of layers of the task is calculated.

**Data Analysis**

The data analysis of this experiment mainly includes the average assembly time and error rate. Data analysis firstly counts the average assembly time of different assembly tasks through experimental video playback, and then performs data screening. It is generally considered that the residual value exceeds 3 times of the standard deviation, which is an abnormal value. After eliminating 4 outliers, the paired t-test and analysis of variance are performed on the sample by SPSS23.0 software, and the significance level is $P<0.05$. To analyze the impact of time pressure and task complexity on production performance.
Result Analysis

Error Rate

The error rates for performing tasks of different complexity at different times are shown in the table. Kruskal-Wallis test analysis found that there was a significant difference between the four types of assembly task completion error rates (H=11.995, P<0.01). Through Mann-Whitney test analysis, it is found that time pressure has a significant effect on assembly task error rate (U=24, Z=-2.031, P<0.01), and task complexity has a significant effect on assembly task error rate (U=15, Z=--2.735, P <0.01).

Table 2. Four Types of Assembly Task Completion Error Rates.

| Task type                  | Error rate |
|----------------------------|------------|
| Low time pressure - simple task | 0.0139     |
| Low time pressure - complex tasks | 0.0076     |
| High time pressure - simple task | 0.0056     |
| High time pressure - complex tasks | 0.0248     |

Average Assembly Time

A paired T-test of the samples revealed that the average assembly time for performing simple tasks at high time pressure (84.633±3.322) was significantly higher than the average assembly time for performing simple tasks at low time pressures (95.267±3.689) (t=-6.066, P=0.004). The average assembly time for performing complex tasks at high time pressure (75.347±8.059) was significantly higher than the average assembly time for performing simple tasks at high time pressure (84.633±3.322) (t=-3.878, P=0.018). The average assembly time for performing complex tasks at low time pressures (63.160±7.200) was significantly higher than the average assembly time for performing complex tasks at low time pressures (75.347±8.059) was not significantly different from the average assembly time for performing complex tasks at low time pressures (63.160±7.200) (t=2.236, P=0.089).

In order to evaluate the impact of time pressure and task complexity on task performance, ANOVA analysis is performed on the change of the average assembly time of different complexity tasks under different time pressures. The results show that complexity has a significant effect on task performance (F(1,16)=60.575, P<0.01), time pressure has no significant effect on task performance (F(1,16)=0.085, P=0.774), there is interaction between them (F(1,16) = 18.410, P = 0.001).

Analysis of Results

Analysis of the four sets of tasks shows that time pressure and task complexity lead to significant changes in assembly task completion error rate and average assembly time. The average assembly time for simple tasks under high time pressure is significantly higher than the average assembly time for simple tasks at low time pressures, while the simple assembly task completion error rate under high time pressure has no significant increase compared with the simple assembly task completion error rate under low time pressure, that is, performing simple tasks under low time pressure has lower production performance. The average assembly time for complex tasks under high time pressure is not significantly increased compared to the average assembly time for complex tasks at low time pressures, while the complex assembly task completion error rate under high time pressure is significantly higher than the complex assembly task completion error rate under low time pressure, that is, performing complex tasks under high time pressure has lower production performance.

Conclusions

Both the error rate and the average assembly time can better assess the level of production performance. The higher the error rate, the lower the performance, that is, the lower the production efficiency. The lower the average assembly time, the higher the performance, that is, the higher the production efficiency.
Considering the error rate and the average assembly time, enterprises should combine time pressure with task types when scheduling tasks. The better solution is to perform relatively simple tasks under high time pressure, while relatively complex tasks should be completed under low time pressure to reduce error rates and improve production performance.

Task complexity has a major impact on the quality of task completion. There is a significant effect on the complexity of the task and the error rate of the operator. The operator has a higher error rate in completing the task with high complexity. Therefore, the enterprise should pay attention to checking the quality of the task with high task complexity in the production process.

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