

Research on Task Switching of Multi-skilled Employees Based on NIRS Technology

Jie Lv¹ Tianpeng Lu^{1,*}

¹ School of Economic and Management, Jiangsu University of Science and Technology, Zhenjiang, Jiangsu 212002, China

*Corresponding author. Email: Tustdoit555@163.com

ABSTRACT

In enterprise production, task similarity and switching frequency have significant effects on employees' brain cognitive load and job performance under dynamic multi task processing. In this paper, Lego car model was used to simulate the manual assembly operation, and a two factor task switching experiment of similarity and switching frequency (2×3) was carried out. The data of oxyhemoglobin (O₂Hb) concentration in left and right prefrontal lobes of 36 subjects were collected by near infrared optical brain imaging equipment (NIRS). The results show that there is no significant difference in the assembly error rate and the total completion time of task similarity, but the dissimilar task will lead to a sharp increase in O₂Hb and an increase in task switching reaction time (RT) compared with similar tasks. Switching frequency had significant effects on task performance and cognitive load. Low frequency switching can improve employee's brain flexibility and reduce brain fatigue caused by repeated assembly. However, task assembly error rate and cognitive load will increase significantly under high frequency switching. The results of this study provide a basis for further understanding the relationship and change of cognitive load and job performance in assembly production. It provides a theoretical scheme for enterprise managers to optimize work plan, reasonably allocate production resources and realize efficient and sustainable production.

Keywords: NIRS, Task switching, Assembly work, Reaction time, Multi-skilled employees.

1. INTRODUCTION

With the continuous penetration of information technology into manufacturing technology, the degree of automation of China's industrial production line has improved significantly, and the production line is gradually developing from monotonic static operation to dynamic multi station operation [1]. Enterprises pay more and more attention to the multi-functional workers who master the skill requirements of multiple stations on the production line and have the ability to operate multiple machines and equipment [2]. On the one hand, dynamic multi position operation mode can effectively reduce human capital and optimize the allocation of production units; on the other hand, multi position task switching will lead to a sharp rise in cognitive load and job satisfaction of employees. In the face of continuous changes in production operations, production line employees need to maintain a high degree of attention, nervous

tension for a long time seriously increases brain cognitive load, significantly reduces work performance, and increases the probability of human error. Continuous production of production line will be forced to interrupt, and even lead to production safety accidents [3]. Therefore, the research on the influence mechanism of task switching in dynamic multi position operation can provide valuable suggestions for reducing the cognitive load of employees, improving work efficiency and ensuring the sustainability of production, and provide important scientific basis for managers in the formulation of standard time of each process and safety production control.

At present, researches on task switching generally show that the indicators of RT and assembly error rate of employees under task switching are worse than those under task repetition, which is called switching cost. On the one hand, many scholars study the heterogeneity of

individual characteristics. Kray [7] considered the differences of subjects' ages; the study found that the switching costs of different age groups when performing task switching are different. The elderly generally produce more switching costs than the young when performing task switching, but with the passage of time, the switching costs of the young generally change more than the elderly. Yang Xiujie [9] considered the differences between gender and emotion, and the experiment proved that men performed better in switching tasks, and the error rate of switching experiments under negative emotions was lower. On the other hand, the research on the influence of external factors on task switching is increasing year by year. Braun [4] established a task switching cost-reward model. Through the analysis of experimental data, it can be seen that employees will pay more efforts only when there is a reward for the task, and the effort cost will increase with the passage of time. Therefore, only when greater reward conditions are provided, employees will make autonomous work switching. Kray [5] found that prior training can effectively reduce the cost of task switching through the mode of training before experiment. On this basis, Xin [6] conducted a 21-day task switching training for 31 students, and found that the cost of task switching was at the lowest level when the task switching experiment was conducted 4 to 6 days after the training, and the longer training time could not make the switching cost continue to reduce, which indicated that the degree of training was not important for the learning transfer effect. Wall [8] measured by simulation experiment that compared with the stable environment, in the turbulent and complex situation, the switching cost will be reduced when the subjects perform the same switching task.

In the above experimental research, domestic and foreign scholars mainly carry out research from the perspective of human factors and external factors, while few scholars analyze it from the perspective of the combination of switching task types and actual production conditions. And many of the above studies require the subjects to switch voluntarily. However, in the actual production, enterprises will strictly formulate the production rhythm and reasonably plan the station sequence, which requires employees to switch tasks in the fixed time and specific station in order, and the task switching is mandatory and normative. Previous literature has shown that there are significant differences in RT, error rate, brain cognitive load between voluntary and forced task switching [10].

With the advent of industrial engineering 3.0-neuro industrial engineering, NIRS, with its high spatial-temporal resolution and other characteristics, effectively integrates human brain current signal as objective data into the scope of production management, and has been widely used in production management, human factors engineering and other fields [11]. Tanaka [12] used the advantage of NIRS real-time data acquisition to quantify the change trend of attention transfer trajectory and brain cognitive load of the operator during task switching assembly. Stéphane [13] demonstrated the unique advantages of NIRS in human brain signal acquisition by measuring the near-infrared spectral data of human body in the state of rest and movement, compared with other brain imaging methods. Han Wenmin [14] conducted an experimental study on the interruption of light manual assembly line through the convenience of NIRS data acquisition, proposed an effective production interruption management strategy, and confirmed the effectiveness of near infrared technology in actual production management. Therefore, this experiment uses efficient and non-destructive NIRS instrument to collect experimental data, simulate the common task switching phenomenon in dynamic multi position operation, and consider the comprehensive changes of job performance and brain cognitive load under the influence of task similarity and switching frequency. It provides a theoretical basis for the research on the cultivation of multi-functional workers on the production line, and has enlightening significance for enterprises to formulate reasonable production plans and realize efficient on-site management.

2. EXPERIMENT

2.1 Purpose

In dynamic multi station operation, employees need to switch tasks repeatedly among multiple processes or machines. Different switching frequency and the similarity of switching tasks have different effects on assembly performance and cognitive load. In order to explore the effect of these factors, the typical LEGO assembly model is selected to carry out the experiment [15]. Through NIRS brain data collection and analysis, we can get the changes of work performance and brain cognitive load under different task types, which can provide guidance for production line site management and product optimization.

2.2 Participants

A total of 36 volunteers (20 postgraduates and 16 undergraduates) were recruited in this study, including 22 males and 14 females, aged 21-26 years (mean = 24.22, standard deviation = 0.895). All the subjects were in good physical condition, with normal naked eyes or corrected visual acuity, without major brain disease and limb disability symptoms, which met the selection requirements of assembly experiment subjects. All the subjects voluntarily signed the consent to participate in the experiment before participating in the experiment.

2.3 Assembly Material

The assembly materials used in the experiment are three LEGO car models with the same difficulty coefficient (serial numbers are 75877, 75878 and 75880 respectively). In order to better simulate the actual production assembly situation and reduce the influence of unrelated actions such as searching and selecting on the experimental data, the parts are placed in the storage box in order of assembly before the experiment (as shown in "Figure 1").



Figure 1 Component layout before experiment.

2.4 Experimental Platform and Equipment

The experimental platform consists of two standard worktables, each of which is equipped with a Lenove desktop computer and a type of LEGO model parts storage box. The distance between the storage box and the subject's body is about 500 mm, which meets the requirements of GB / t13547-1992 "dimensions of human body in working space". The LEGO model assembly step diagram is shown on the desktop computer display (as shown in "Figure 2").

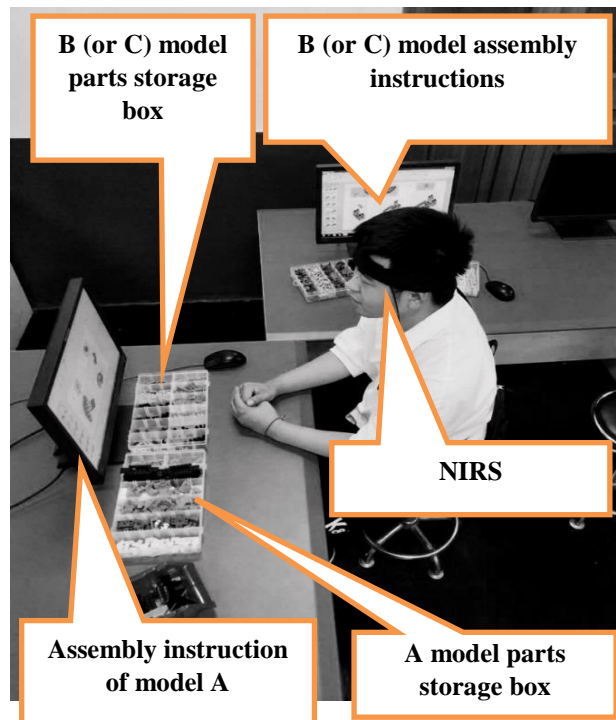


Figure 2 The chart of operation site.

2.5 Experimental Process

After the subjects arrive at the laboratory, they rest for 2 minutes, and then the experimental recorder explains the relevant experimental process and operation precautions to the subjects. Before the formal experiment, the subjects need to read and sign the "experimental consent". Each subject had 15 minutes of LEGO car model assembly practice time. After reaching the proficiency level, the formal experiment was carried out.

The experiment involves the assembly of three Lego models, which are represented by letters A, B and C for the convenience of narration. Model A represents the rear of LEGO model 75877, model B represents the rear of LEGO model 75878, and model C represents the front of LEGO model 75880 (as shown in "Figure 3"). According to the similarity system theory, AB model is similar (similarity is 0.6871), AC model is not similar (similarity is 0.3531).

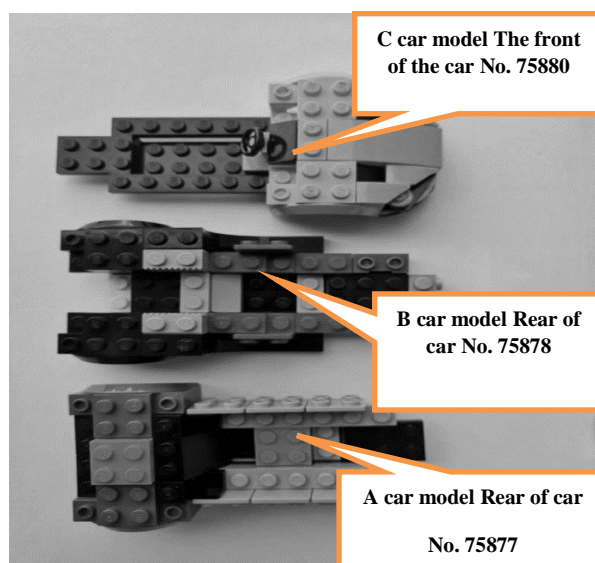


Figure 3 Appearance of each model after assembly.

In the experiment, 36 subjects were randomly divided into two groups. The first group was used to assemble similar tasks (assembly A model and B model), and the second group was used to assemble dissimilar tasks (assembly A model and C model). In assembly experiment, task switching frequency is divided into three levels: repetition, low frequency switching and high frequency switching.

Each subject in the two groups needs four rounds of assembly, and each round has six models, that is, each subject needs to assemble 24 models in total. The specific assembly arrangement is shown in "Table 1". Every time the participants complete a round of assembly, they will get a rest time of 5 minutes, and it takes about 1.5 hours for each participant to complete all the assembly tasks.

Table 1. Experimental plan and assembly task description

Task arrangement of assembly experiment		Assembly model and quantity
Group 1: similar task group	First round	AAAAAA
	Second round	BBBBBB
	The third round	AAABBB
	The fourth round	ABABAB
Group 2: dissimilar task group	First round	AAAAAA
	Second round	CCCCCC
	The third round	AAACCC
	The fourth round	ACACAC

2.6 Data Analysis

The data analysis of this experiment includes behavioral data analysis and brain cognitive load data analysis. Two subjects' experimental data were excluded. During the experiment, one of the subjects did not carry out the assembly experiment according to the specified operation steps, and the experimental data deviation was too large; the other subject had the problem of NIRS equipment signal interruption, and the experimental data could not be collected completely and continuously.

In the experiment, the behavior data is collected mainly through the experimental video playback stored by Nikon camera to determine the assembly time of each round of the experiment. The assembly error rate was determined by comparing the actual assembly model with the operation manual model. Brain cognitive load data are collected by portalite near-infrared optical brain imaging equipment. Before analyzing the near-infrared data, oxyon software needs to be used to filter the original data to avoid the influence of laboratory noise and personal physiological interference. Then, the experimental data were imported into Matlab software to calculate the relative concentration of O₂Hb in the left and right prefrontal regions of the subjects in each round of the experiment, and the relative concentration of O₂Hb in the left and right prefrontal regions of the subjects in the resting state

was subtracted from the value, and the obtained Δ O₂Hb data was the relative concentration change of O₂Hb during the switching experiment. All data were imported into IBM SPSS 22.0 for analysis, and the significance level was $p < 0.05$.

3. EXPERIMENTAL DATA ACQUISITION AND PROCESSING

3.1 Assembly Time

The assembly time of each experimental group is shown in "Table 2". It can be seen from the table that there is no significant difference in assembly time among A, B and C models under repeated assembly, and the assembly time decreases with the increase of assembly times. The influence of similarity and switching frequency on assembly time was analyzed, and independent sample t-test was conducted. It was found that assembly time of high-frequency switching task was significantly higher than that of low-frequency switching task ($t(32) = 0.513, P < 0.05$), and there was no significant difference between assembly time of dissimilar task and that of similar task ($t(32) = 0.712, P = 0.566$).

Table 2. Assembly time results of each experimental group

Assembly quantity	Assembly time							
	Repeated assembly A	Repeated assembly B	Similar low frequency	Similar high frequency	Repeated assembly A	Repeated assembly C	Dissimilar low frequency	Dissimilar high frequency
1	167.59	164.21	158.12	162.59	166.11	165.24	160.63	164.27
2	156.97	156.49	149.31	161.99	155.87	156.47	150.05	159.68
3	151.14	147.13	144.96	165.39	149.68	150.21	148.65	165.07
4	146.63	143.87	159.99	164.32	146.59	145.77	158.94	164.57
5	143.32	139.12	152.57	167.25	143.06	140.32	153.57	167.85
6	140.67	137.58	146.84	166.11	139.87	137.85	148.39	167.47

3.2 Reaction Time (RT)

The RT of this experiment starts with the completion of model A assembly, and ends with the switch to model B (or C) and the completion of the first three assemblies. The time span is RT.

The RT statistical results of different types of tasks are shown in "Table 3". Under high frequency switching, the RT of dissimilar tasks and similar tasks decreases with the increase of switching times. Calculate the mean value of RT under different task types (high frequency switching is calculated by dividing the sum of three RT by 3).

The calculation results are shown in "Figure 4". The two-way ANOVA method is used to compare the effects of task similarity and task switching frequency on RT. The results show that similarity has a significant impact on RT ($F(1,64) = 4.629, P < 0.05$). Switching frequency also has a significant impact on RT ($F(1,64) = 4.629, P < 0.05$). There was no interaction between the two factors ($F(1,64) = 0.020, P = 0.887$).

Table 3. Reaction time of task switching under different task types

Task type	Assembly task RT	
	Mean value	Standard deviation
Similar low frequency	10.716	2.034
The first switch under similar high frequency	10.484	2.078
The second switch under similar high frequency	9.304	1.982
The third switch under similar high frequency	8.565	2.267
Dissimilar low frequency	11.589	1.885
The first switch under dissimilar high frequency	11.462	1.852
The second switch under dissimilar high frequency	10.241	1.392
The third switch under dissimilar high frequency	9.641	1.372

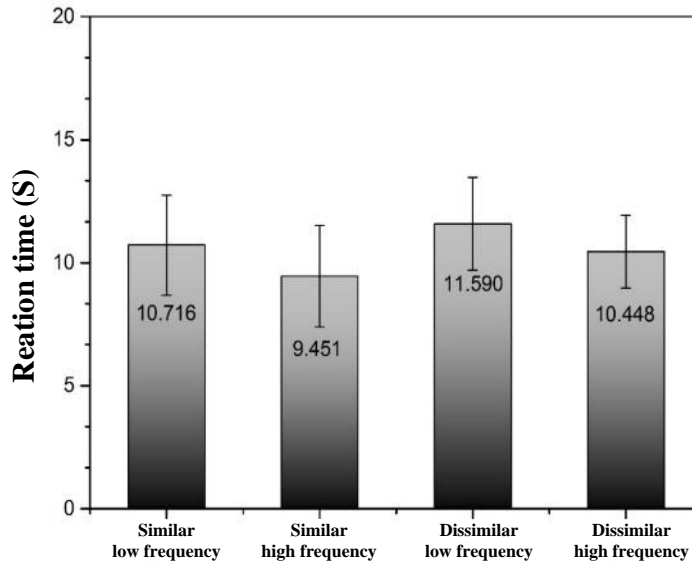


Figure 4 Comparison of the average Reaction time under different task types.

3.3 Error Rate

When the participants assembled LEGO model, the color, shape and assembly direction of the parts were inconsistent with the schematic diagram of the assembly instructions, which all identified that the assembly step was wrong. The expression of

assembly error rate is $\frac{N_1}{N}$, where N_1 represents the number of assembly error parts of each car model, and N represents the total number of parts of this type of car model. The error rate of the experimental group under different types is shown in the "Table 4" below.

Table 4. Error rate of LEGO model assembly under different task types

Task type	Assembly error rate of the first three vehicles	Assembly error rate of the last three vehicles	Total error rate
Repeated task A in the first group	0.078	0.133	0.106
Repeated task B	0.08	0.115	0.098
Repeated task A in the second group	0.089	0.122	0.106
Repeated task C	0.086	0.129	0.108
	A task error rate	Switching tasks (B or C error rate)	Total error rate
Similar low frequency task	0.078	0.08	0.101
Similar high frequency task	0.111	0.126	0.125
Dissimilar low frequency task	0.089	0.086	0.087
Dissimilar high frequency task	0.122	0.172	0.147

K-W test is used to analyze the assembly error rate of four groups of repeated tasks. The results show that there is no significant difference in the overall assembly error rate of A, B and C models under repeated assembly tasks ($H = 0.082$, $P =$

0.651). However, according to the statistical results of error rate, with the increase of time, the error rate of repeated assembly increases significantly. When the switching frequency of assembly tasks is different, the error rate of assembly tasks increases

significantly and there is a big difference ($F(1,64) = 10.862, P < 0.05$). But similarity had no significant effect on the error rate of assembly task ($F(1,64) = 3.615, P = 0.62$).

3.4 Near Infrared Brain Cognitive Load Data

In this experiment, the concentration of O_2Hb in the prefrontal region of the left and right brain was collected by portable near-infrared optical brain imaging equipment, and the effect of similarity and switching frequency on brain cognitive load of employees during task switching was evaluated by analyzing the changes of O_2Hb concentration during the experiment ("Figure 5" and "Figure 6").

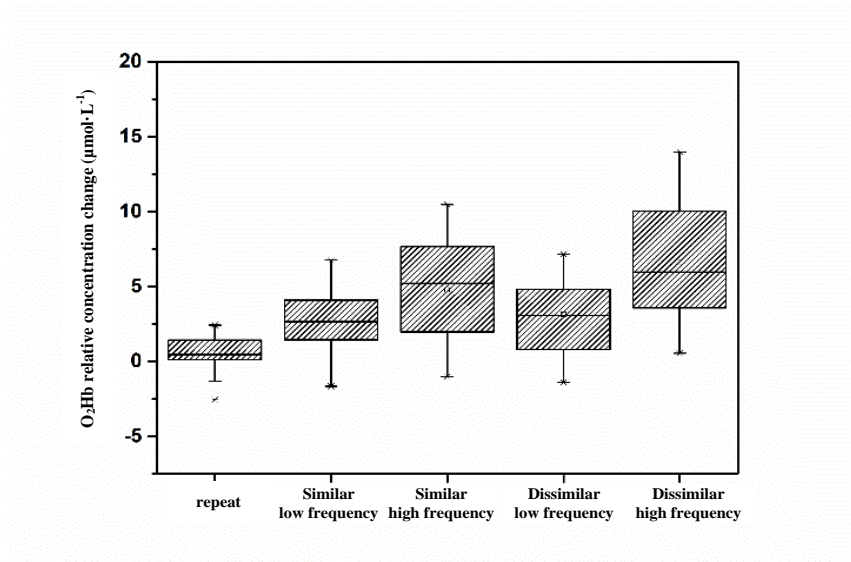


Figure 5 Changes of relative concentration of O_2Hb in the right prefrontal cortex of different task types.

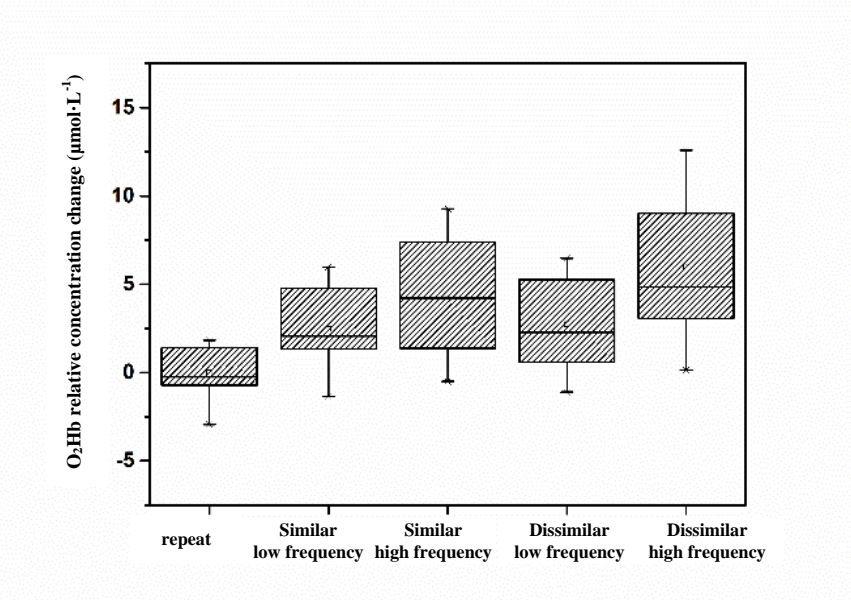


Figure 6 Changes of relative concentration of O_2Hb in the left Prefrontal cortex of different task types.

The relative concentration of oxyhemoglobin (O_2Hb) was analyzed by two-way ANOVA. In the right prefrontal cortex, task switching frequency

had a significant effect on the relative concentration of O_2Hb in the right brain ($F(1,64) = 16.821, P < 0.05$), task similarity had a significant effect on the

relative concentration of O₂Hb in the right brain ($F(1,64) = 8.563, P < 0.05$), and there was no interaction between them ($F(1,64) = 0.871, P = 0.354$). In the left prefrontal region, task switching frequency had a significant effect on the relative concentration of O₂Hb in the left brain ($F(1,64) = 14.584, P < 0.05$), task similarity had a significant effect on the relative concentration of O₂Hb in the left brain ($F(1,64) = 7.591, P < 0.05$), and there was no interaction between them ($F(1,64) = 0.732, P = 0.395$).

3.5 Discussion

Combining behavioral data and near-infrared data, four indicators were used to analyze the effect of different types of task switching. The results showed that near-infrared indicators were significantly affected by task similarity and switching frequency. The relative concentration of O₂Hb in the left and right prefrontal cortex was significantly higher in the dissimilar task (or high-frequency switching task) than that in the similar task (or low-frequency switching task), which was mainly due to the fact that there were many similar cues related to the target memory in the similar task. According to the inertia theory of task setting, it was not necessary to completely disrupt the cognitive coding process of employees in the task switching. When switching dissimilar tasks, more cognitive resources need to be allocated to reconstruct task settings in the process of recognition and coding. Moreover, with the increase of switching frequency, the number of cognitive coding times and the consumption of cognitive resources increase significantly. Therefore, employees need to bear more cognitive load to complete dissimilar tasks or high-frequency switching tasks. This conclusion is consistent with the previous research conclusion of attention focus switching mechanism [17], which provides an experimental basis for the theoretical research on the mechanism of task switching cost.

For the analysis of assembly time and RT index, it is found that the switching frequency has a significant impact on the total assembly time and RT, and the similarity has a significant impact on RT, but has no significant impact on the total assembly time, which is inconsistent with the previous research that similar task combination can effectively reduce the completion time of production tasks. The main reason is that the LEGO model used in this experiment has certain assembly complexity. In each LEGO model experiment, the

operator needs to pay a long time cost, and the influence of task similarity is further weakened. Under the condition of high-frequency switching, although the total assembly time of tasks is prolonged, the RT is decreasing. This phenomenon is generally explained as the existence of a rapid control transformation system from the initial abstract rule representation to the actual representation in the brain. The system can make the brain quickly adapt to simple cognitive behavior or action behavior through one or two repeated switching activities without long-term repetition [18].

As for the error rate index, by analyzing the assembly status of the last three models with repeated tasks in each group of experiments, it can be seen that as the assembly time goes on, the assembly operation tends to be an inertial operation, and the assembly error rate gradually increases, which is consistent with the research results of many scholars [19]. That is to say, continuous monotonous and repetitive work will lead to the decrease of work performance, which further indicates the necessity of studying task switching in dynamic multi position production. However, the error rate of high-frequency switching task is significantly higher than that of low-frequency switching task, which indicates that the operators who experience high-frequency switching pay much less attention to assembly task than those who experience low-frequency switching.

4. CONCLUSION

By designing a two factor assembly experiment of similarity and switching frequency (2×3), this paper simulates the task switching mode under dynamic multi position production in actual production, and analyzes the different effects of task switching frequency and task similarity on the cognitive load and task performance of employees in assembly industry by combining portable near infrared optical brain imaging technology. It is summarized as follows:

- Although single repetitive assembly has the advantage of inertia in the early stage of production, the total assembly time of task is significantly shorter than task switching. However, as the production time goes on, the cognitive load of brain increases and task performance decreases. Task switching can effectively reduce the fatigue of monotonous work and improve the ability of efficient and sustainable work,

but due to the existence of switching cost, task switching will increase the total task completion time. Therefore, in the actual production, enterprises should comprehensively consider the product qualification rate and employee job satisfaction, try to avoid using the single repeated operation production mode, effectively implement the multi station rotation mechanism, and appropriately improve the switching frequency of similar stations, which is of great significance for improving the production efficiency of enterprises.

- Task switching frequency has a significant impact on cognitive load and task performance of employees in assembly operation. High frequency task switching results in a sharp increase in O2Hb concentration and assembly error rate. Therefore, when the enterprise formulates the production task allocation table, it can't deliberately make a one person multi post plan to reduce the labor cost. That is to say, the production task arrangement should not only avoid that the employees are always in the state of repetitive production, but also avoid that the employees frequently switch in multiple processes or machines in unit time. Reasonable distribution of production processes can achieve efficient production.
- Task similarity has a significant effect on the cognitive load of the assembly workers. Therefore, when the enterprise arranges the production plan, it should give priority to assign similar tasks to each employee. At the same time, in the multi-functional training guidance, enterprises should consider under the condition that the mental load of employees is controllable, so that the multi-functional workers can be competent for similar work as far as possible, in order to avoid the high error rate of multi task processing.

By using LEGO model to simulate manual assembly, physiological data measurement equipment was used to quantify employees' brain cognitive load, and the effects of task switching frequency and task similarity on employees' brain cognitive load and job performance were explored. The research results have practical guiding significance for optimizing production planning and allocating production resources reasonably. In the future research, we can turn the research of task switching in assembly production to the research of task switching in human-computer interaction.

From the perspective of multi person cooperation, we can comprehensively consider the impact of task switching on group work performance. Combined with the specific production situation of the enterprise, the paper further provides theoretical basis and suggestions for the enterprise production planning and personnel post matching.

AUTHORS' CONTRIBUTIONS

Tianpeng Lu was responsible for experimental design, analysed data and wrote the manuscript, and Jie Lv contributed to revising and editing.

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