Effects of Spaceflight Operation Complexity and Training on Operation Error

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Abstract. To investigate how the spaceflight operation complexity and training affect operation errors of spaceflight tasks, a two-factor experiment was designed and conducted. Nine participants performed eighteen spacecraft operation units which were divided into three complexity levels during two training stages. Based on the experiment data, the changes of average operation times and errors at the initial and final stages were analyzed; the equations of linear regression between the complexity and the average operation errors were established. The results showed that the average operation errors were significantly raised with the complexity at the initial stage (P=0.03, 0.02). The operation errors of the low and middle complexity levels at the final stage were much less than those at the initial stage ($P<0.05$).The operation errors were significantly correlated to the complexity levels at the two stages. It implies that suitable operation complexity and sufficient training are two of the effective ways to ensure the reliability of astronaut operations during spaceflight.

Keywords: training, operation complexity, operation error, correlation.

1 Introduction

Chinese Manned space program has progressed rapidly after four manned space missions from SZ-5 to SZ-9. The goal of Space Medicine and Medical Engineering has been extended from ensuring the astronauts' safety and health in the early stage to ensuring their working capabilities, improving the operational reliability and maximizing astronauts' contributions.

In space, astronaut, manned spacecraft and space environment constitute a typical man-machine-environment system. All the three aspects are significant to the accomplishment of flight missions. Human aspects: psychological state and training effect will affect the accomplishment of flight mission directly. Machine aspects: inappropriate position of panel or insufficient light will influence the manual control space

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V.G. Duffy (Ed.): DHM/HCII 2013, Part I, LNCS 8025, pp. 118–125, 2013.

operation. Environment aspects: weightlessness, noise or radiation will affect the spatial orientation and the movement control ability of astronauts [1]. Therefore, for manned spaceflights, the reliability of human in system will be particularly important.

Spaceflight operation complexity and training are regarded as the two main influencing factors on astronaut operation error by some previous researches. To improve the training effects of spaceflight operation and finally ensure the reliability of astronaut operation in orbit, a series of researches were conducted in this work to investigate how the two factors affect operation errors of spaceflight tasks. This study would provide theoretical guidance for the design of spaceflight tasks and astronaut training methods in the future, and then the potential human errors in manned spaceflight could be prevented effectively.

2 Method

A two-factor experiment was designed in this study. The independent variables were operation complexity and training. The dependent variable was the number of operation errors which was defined as a deviation from the required action following the operation procedure in this study.

2.1 Participant

Nine male test subjects were recruited from China Astronaut Research and Training Center. They had no operation experience of spaceship panel and Environment Control and Life Support System (ECLSS). All the subjects passed a cognitive test by a multi-dimension psychological test instrument named DXC-VI. The experiment was approved by the ethics committee of China Astronaut Research and Training Center.

2.2 Operation Complexity Evaluation and Operation Unit Selection

Participants were asked to finish 18 simulated spaceflight operation units in the spacecraft panel training platform and ECLSS training platform. The operation complexity of each operation unit was evaluated by entropy based method and subjective evaluation method.

Operation Complexity Evaluation. Xing and Manning reviewed the literature on complexity including articles on general concepts, information complexity, cognitive complexity, and display complexity, and then presented that, while these studies were focused on different areas, they all agreed on three factors associated with complexity: the quantity of basic information elements (size), the variety of elements (variety), and the relationship between elements (rule) [2, 3]. Based on that, the spaceflight operation complexity was defined in previous studies as, the combination of operation tasks, the quantity and the variety of basic information elements and the relationship between the elements included in operation interface. The spaceflight operation complexity can be perceived by astronaut and affect the operation performance. The operation complexity in this study was not related to human factors and environment factors, such as the ability and experience of astronaut and the effect of weightlessness [4, 5].

Subjective and objective evaluation methods were used to determine the complexity level. Subjective evaluation method was implemented by experts' assessments. Objective evaluation method is entropy based method. Finally, the complexity level was determined in terms of the consistent principle of subjective and objective evaluation results. The weighted method would be used to process the results if they were not consistent and the final result would be the complexity value.

On the basis of complexity evaluation index system, a kind of complexity evaluation method based on entropy measure was established (entropy based method for short) [6]. The following four factors were selected to describe the operation complexity: complexity of operation step size (COSS), which evaluates the amount of actions contained in one operation unit, complexity of operation logic structure (COLS), which describes the logical sequence to conduct the activities of one operation unit, complexity of operation instrument information (COII), which denotes the type and number of monitors and controllers in one operation unit, and complexity of space mission information (CSMI) which is related to the difficulty level of the task information for completing one operation unit. Finally, the operation complexity values of spaceflight operations were determined by the weighted Euclidean norm of the four factors [4, 5].

Subjective evaluation method was implemented by experts' assessment. The twelve first batch of astronauts and five main faculties in charge of flight procedure training were recruited into the expert group to evaluate the complexity of each operation unit on a nine-point scale. The average is regarded as the final result of subjective complexity evaluation.

In terms of the complexity range of spaceflight operations, the value of high complexity level is between 2.0 and 2.5, the value of middle complexity level is between 1.5 and 1.8, and the value of low complexity level is between 0.8 and 1.2.

Operation Unit Selection. According to the experiment condition, equipments and operability, the complexities of 25 space operation units initially selected were then evaluated by subjective and objective evaluation methods. Following the consistent principle of subjective and objective evaluation, eighteen operation units were selected for the final experiment. All the units were divided into three operation unit groups. Three spacecraft emergency operations and three ECLSS operations were involved in each group. Each type of operations involved three complexity levels.

2.3 Equipment and Procedure

The experimental equipment included a spacecraft panel training platform, an ECLSS training platform and a data recording software. Participants performed operations on spacecraft panel training platform and ECLSS training platform, in which the operation units could be chosen and the operating states could be recorded. The data recording software were used to record the operation errors and performance of each operation.

The preliminary instruction and basic theories were taught to the participants before the experiment. The formal experiment consisted of initial stage and final stage. Except for the targeted theory instruction and training comment, each participant finished six operation units in each group. Each operation unit was performed five to six times in order.

2.4 Data Processing and Statistic Analysis

The experiment data were processed using Paired Sample T Test in SPSS 15.0.

For each operation unit, the average number of operation errors during the first three times at the initial stage was regarded as the initial training effect and that of the last two times at the final stage was regarded as the final training effect. The changes of average number of operation errors at two stages were analyzed. The equations of linear regression between complexity and average operation errors were established and the coefficients were compared. $P<0.05$ means the difference is significant. $0.05<P<0.1$ means the trend of significant is different.

3 Result

The analysis result of performance shows that the operation success rate was between 98% and 100%, and the operation errors between different participants had no significant statistic meaning. Therefore, the accuracies of all the participants were regarded as high and similar. Based on that, the operation errors were analyzed.

3.1 Comparison between Average Operation Times of Different Complexity Levels at Different Training Stages

Table 1 shows the result of comparison between average operation times of different complexity levels at different training stages. The average operation times of the middle and high complexity levels were more than those of the low complexity level ($P<0.01$). The average operation times of high complexity level were more than those of the middle complexity level ($P<0.05$). These results accorded with the discipline that the operation time prolongs when the complexity level increases. Therefore, the complexity evaluation method used in this study could be proved effectively.

Table 1. Comparison of average operation time of different complexity levels at different training stages ($\overline{x} \pm s, n = 9$)

Complexity level	Initial stage	Final stage	P value
Low	19.90 ± 11.52	14.75 ± 1.60	0.26
Middle	$133.70 \pm 3.00^{\Delta\Delta}$	$64.36 \pm 9.48^{\Delta\Delta}$	<0.01
High	$188.83 \pm 15.23^{\Delta\Delta\#}$	$78.88 \pm 13.34^{\Delta\Delta\#}$	<0.01

Note. $^{\Delta\Delta}$ $P<0.01$, as compared with operation time of low complexity level at the same stage ;

$^{\#}$ $P<0.05$, as compared with operation time of middle complexity level at the same stage.

3.2 Comparison between Average Operation Errors of Different Complexity Levels at Different Training Stages

Table 2 shows the result of comparison between average operation errors of different complexity levels at different training stages. The average operation errors of middle complexity level were more than those of low complexity level significantly (P<0.05) at both training stages. At the initial stage, the average operation errors of high complexity level were more than those of low complexity level significantly, while no significant difference existed with those of middle complexity level. At the final stage, the average operation errors of high complexity level were not significantly different with those of middle and low complexity levels. The average operation errors of middle and low complexity levels at the final stage were less than those at the initial stage significantly (P<0.05). For the high complexity level, the variation trend is significant (P=0.064).

Table 2. Comparison of average operation error of different complexity levels at different training stages ($\bar{x} \pm s, n = 9$)

Complexity level	Initial stage	Final stage	P value
Low	0.35 ± 0.04	0.04 ± 0.03	<0.001
Middle	1.28 ± 0.45$^{\Delta}$	0.11 ± 0.06$^{\Delta}$	<0.05
High	1.99 ± 0.58$^{\Delta}$	0.50 ± 0.66	0.064

Note. $^{\Delta}$ P<0.05, as compared with operation errors of low complexity level at the same stage.

3.3 Correlation between Operation Complexity Levels and Operation Errors at Different Training Stages

The equations of linear regression between the operation complexity levels evaluated by entropy based method and the operation errors of each participant on each operation unit are established at both the initial and final stages. Table 3 shows that the regression coefficients and correlation coefficients both decrease at the final stage, compared with those at the initial stage (P<0.05). This result demonstrates that the opposite effect of complexity level on operation error reduces after a series of training.

Table 3. Correlation between operation complexity levels and operation errors at different training stages

Complexity measure method	Equations of linear regression		P value
	Initial stage	Final stage	
Entropy based method	Y=6.31X-4.47	Y=0.492X-0.302	<0.05
	R^2=0.607, P<0.001	R^2=0.241, P=0.038	

Note. Y, operation errors. X, operation complexity level. P, the value of statistical test probability between regression coefficient of function at the final training stage and that at the first training stage.

4 Discussion

The definitions of complexity in different research fields are different. This study defined the operation error according to the need of astronaut training and the feasibility of measurement and established a complexity evaluation method based on entropy measurement. On the basis of the evaluation model, the effects of spaceflight operation complexity and training on operation error were investigated.

Table 1 shows that with the increase of complexity levels, the operation time lengthened at two stages. Therefore the complexity evaluation method could be regarded as valid. At both the initial and final stages, the average operation errors of middle and high complexity levels were more than those of the low complexity level. Consequently, the operation complexity can be considered as a main influencing factor of operation errors. In space, with the increase of the operation complexity, the requirement on attention and coordination between eyes, hands and brains are more demanding. Meanwhile the astronauts' workload will be heavier, severely affecting the final performance. However, there was no significant difference of operation errors between the middle and high complexity levels. The conceivable reason is that the complexity gap between the two complexity levels is not big enough to reveal the different effects of complexity.

The comparison between Table 1 and Table 2 shows that the differences of operation times are more significant than those of operation errors of different complexity levels. Therefore, the complexity evaluation method used in this study may be more effective on evaluating operation time.

Table 2 shows that the average operation errors of low and middle complexity levels decreased significantly at the final stage ($P<0.05$). This result shows with the training, the operation reliability was enhanced apparently. The occurrence of operation error is closely related to the time of training and the proficiency of skills. Therefore, to ensure the operation reliability in spaceflight, plenty of strict and effective training activities are necessary for astronauts [7]. However the operation errors of high complexity level did not decrease significantly with the proceeding of training. It means that more training is needed to master the high complexity operations.

Table 3 shows that the regression coefficients and correlation coefficients of the equations both decreased at the final stage, compared with those at the initial stage ($P<0.05$). This result shows that the training have a significant effect on the correlation between the operation complexity and operation errors. The ergonomic perspective on human error is that errors arise as a result of incompatibility between the characteristics of the human and task demands [8].Thus, any mismatch between operation capability and task demands will increase error occurrence and potentially challenge safety [9]. One of the basic approaches to managing human error is to establish compatibility between people's capabilities and task demands by using appropriate selection and training methods [10]. Therefore training was one of the countermeasures to decrease the effect of task complexity.

Park et al. noted that the significant correlation between complexity and operation times and errors is the leading basis of judging the effectiveness of complexity evaluation method. If the significant correlation exists and the operation time and error increase with the enhancement of complexity level, then the complexity evaluation method will be regarded as valid and it can be used to predict the operation time and error rate [11,12]. The results of Table 1 and Table 2 show that the variation of operation time and error with the enhancement of complexity level is in accordance with the theory Park presented. Therefore the entropy based method used in this study is valid.

To sum up, this study shows that spaceflight operation complexity and training are of significant effects on operation errors. The complexity evaluation method based on entropy measure is valid in different training stages. However, the influence of training should be considered before predicting the situation of operation error by complexity evaluation. According to the study on effects of spaceflight operation complexity and training on operation error, operation units with high complexity level were verified to lead to astronaut operation error more easily. But with the proceeding of training, operation error rate was reduced apparently. Therefore, high complexity level operations should be avoided when spaceflight missions are designed and arranged. For inevitable high complexity missions, operation skills should be grasped firmly by repeated training. Because of the difference of training stages, the factors have effects on astronaut operation error changes constantly. Consequently, actual flight condition and mission difficulties at different training stages should be taken into account to design pertinent training method. The results in this study provide an important guidance for the design of astronaut training plan in the future and for accomplishment of training mission with high quality with limited time and resource.

Acknowledgements. This work was supported by National Natural Science Fund project (71001092) and National Basic Research Program of China (2011CB711000) and the foundation of National Key Laboratory of Human Factors Engineering (HF2011Z-ZB-04).

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