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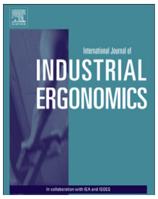

Predictive capability of cognitive ability and cognitive style for spaceflight emergency operation performance

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ABSTRACT

This study explores the effects of cognitive ability (information seeking, inference, spatial recognition, attention span, and attention allocation) and cognitive style (active-reflective, sensing-intuitive, visual-verbal, and sequential-global) on task performance of simulated spaceflight emergency operations that require judgment and operation on a Chinese spaceflight instrument board and the possible interaction effect with training experience. The performance criteria included task completion time and number of human errors. It was found that inference ability, spatial recognition ability, and attention span had significant effects on task completion time, while attention allocation ability had significant effect on the number of error. The participants with a sequential cognitive style made significantly fewer errors than those with a global cognitive style. Training experience significantly decreased task completion time. The participants with sequential cognitive style learnt faster than those with global cognitive style in the spaceflight instrument operations. With increasing training experience, the predictive capability of cognitive ability on performance decreased, whereas the predictive capability of the sequential-global cognitive style on performance increased.

1. Introduction

Spaceflight exploration and human activities in space have been increasingly garnering interest worldwide. Safety is extremely important for completing spaceflight mission successfully. Since humans are difficult to be controlled (Li, 2011) and error-prone, no matter the spaceflight is under normal conditions or emergency situations, human error is a significant issue. Once a human error occurs or an emergency has not been solved within the prescribed time period, mission could fail even cause catastrophic accidents (Nelson, 1999).

Traditionally, there are mainly four ways to improve human reliability. First, it is more emphasized on designing aerospace system interfaces, equipment, and operation procedures to make them with higher usability and more user-friendly for humans, even to prevent human error or be robust to human errors (Seastrom et al., 2004; Zhang et al., 2011). Second, from the aspect of organization and administration, human error can be reduced by establishing proper management systems and operation specifications. Third, training programs provide opportunities to develop humans' potential, improve certain abilities and enhance performance. For example, the training program developed by the German Aerospace Research Establishment covers communication and cooperation, stress management, coping with operational demands, effective problem solving in groups, and problem-oriented team supervision (Manzey and Schiewe, 1992). At last, the persons who are the most likely to be competent for spaceflight mission can be selected by measuring their individual characteristics such as cognition, emotion, motivation, empathy psychomotor ability, etc.

The particular interest of this study relates to the latter two ways. Traditionally, training programs and selection criteria are developed mainly based on operation experience and knowledge of domain experts. The effects of specific individual characteristics on performance has never been studied systematically and verified sufficiently. The question is raised that what individual characteristics are more crucial to spaceflight safety, especially under emergency situations. That is quite important for establishing the weights of selection indices and the priorities of training contents.

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The answer of this question would be of great help to improve the existing personnel selection and training standard, and for astronauts to build skills and obtain experience more effectively.

People tend to be easier to notice the individual differences in physical appearance rather than the differences in their cognitive ability and cognitive style. Nevertheless, it is the latter largely influencing people's thinking, feeling, learning and behaviour. Studies have shown that cognitive ability and cognitive style can predict learning outcomes (Jonassen and Grabowski, 1993; Ackerman, 2007; Komarraju et al., 2011) and job performance (Hollnagel, 1998; Schmidt and Hunter, 1998; Hough and Furnham, 2003; Poropat, 2009), and are significantly related to the comprehension of domain information generated from a process model (Recker et al., 2014). It was found that cognitive ability significantly impacts diagnostic performance (Burkolter et al., 2009a) and system control performance (Burkolter et al., 2009b) in a simulated cabin air management system, firefighters' performance in extinguishing fires (Henderson, 2010), and human performance in nuclear power plants (Zhang et al., 2013). Ovaskainen and Heikkilä (2007) explored the cognitive abilities of the timber harvester operators and suggested that abilities including comprehensive perception, wide use of memory functions, non-verbal deduction, spatial perception, coordination, concentration and motivation should be evaluated when selecting new harvester operators.

The role of cognitive style has also been conducted in various domains, such as management, industry, and education (Cassidy, 2004; Dong et al., 2008). For example, thorough understanding of users' cognitive search strategies could provide valuable insights to website and search engine developers (Thatcher, 2006). Users' cognitive searching behaviour was found to be related to their cognitive styles (Hariri et al., 2014). Index of Learning Styles (ILS) proposed by Felder and Silverman (1988) is widely used to test individual's cognitive style. It classifies people into one category or the other in each of the following four dimensions: active-reflective, sensing-intuitive, visual-verbal and sequential-global. The four dimensions reflect an individual's speed and accuracy of making a decision under uncertainty, preference type of information perception, pattern of information representation, and strategy for information processing, respectively. Moreover, it has been found that when the task environments match the cognitive style, individuals perform better in problem-solving measures (Katz, 1990), information recall and use (Sprehn et al., 2013), and academic achievement (Kolb, 2014; Dunn et al., 2002). Torenvliet et al. (2000) examined the interaction between cognitive style and type of interface, and found that the participants with holist cognitive style using an interface with ecological interface design (EID) performed best. Rau et al. (2004) suggested that appropriate interfaces should be designed to accommodate users with different cognitive styles to enhance human performance when using computer. It was generally accepted that cognitive style and the matching of cognitive style with task environment influenced task performance and outcomes.

A growing body of research supports that cognitive ability and cognitive/decision-making style are likely to play a vital role in spaceflight mission success, particularly in emergency situations (Collins, 1985; Manzey et al., 1995; Morphew, 2001; Musson et al., 2004; Dion, 2004; Musson and Helmreich, 2005; Kanas et al., 2009). However, there is not a systematic study to examine the relative importance of different cognitive ability aspects and cognitive styles in spaceflight emergency operations yet. The aim of our study is to examine the relationship between various aspects of cognitive ability/cognitive style and instrument board operation performance under emergency situations as well as the potential interaction effect of training and cognitive ability or cognitive style.

2. Methods

2.1. Participants

This study recruited 30 male students who were studying aeronautical and astronautical engineering at Tsinghua University. Right-handed and no experience of instrument operation were required. Three participants did not finish the entire experimental process. The results in this study are based on data from 27 students aged from 20 to 26 (mean: 23.2; SD: 1.45) with the height from 165 cm to 175 cm. The participants were required to have slept well and ensure alcohol was not consumed one day before the experiment. The participants were informed about the details of the experimental protocol and voluntarily signed informed consent forms before the experiment proceeded. Prior to data collection, the participants provided their basic demographic information.

2.2. Experimental platform

This study was conducted in an astronaut training room in China Astronaut Research and Training Centre. The room was a simulated spacecraft environment which is the same as a real spacecraft. The experimental platform was an instrument board in this astronaut training room. The spaceflight process, which includes normal flight, autonomous emergency return and escape from flight, can all be simulated in this platform. The platform provides instrument information display and event notifications. It can also simulate a variety of spacecraft fault states. With the setting function, the training process can be well controlled, such as setting up or removing a failure. More importantly, the actions of the participants on the station can be recorded by the system automatically in real time. The components involved in this experiment included two monitors, two control panel units, two cabin wall units, and a portable control unit. The two monitors were used to present the parameters/statuses of 12 spacecraft subsystems. Because there were so many parameters/statuses, the parameters/statuses of each subsystem had to be presented on 1 to 3 pages with words and numbers.

The sketch of the experimental platform is shown in Fig. 1, where white boxes represent small dial plates and displays not used in this study. Because of confidential consideration, a real picture of the experimental platform is not allowed to be presented here.

2.3. Experimental task

The experimental task was to execute emergency operation procedures on the instrument board under nine simulated malfunction conditions. They were separation malfunction, monitor display malfunction, electrical power malfunction, GNC (guidance, navigation and control) system malfunction, environmental control system malfunction A (total pressure), propulsion system malfunction, thermal control system malfunction, environmental control system malfunction B (oxygen partial pressure), and comprehensive malfunction. For each emergency operation, paper-based operation procedures were provided to the participants as shown in Fig. 2(a). The participants were asked to observe the spacecraft information from the monitors, find the subsystem page involved, view the state of the required components, and operate 8 different types of buttons/switches distributed on the manual control panel units, cabin wall units or portable unit.

2.4. Experimental procedure

Fig. 3 summarizes the entire experimental procedure. Before the