International Journal of Industrial Ergonomics 54 (2016) 48–56

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

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

Dan Pan [a, b, 1], Yijing Zhang [b, *], Zhizhong Li [a, 2]

[a] Department of Industrial Engineering, Tsinghua University, Beijing, 100084, PR China
[b] National Key Laboratory of Human Factors Engineering, China Astronaut Research and Training Centre, Beijing, 100094, PR China

ARTICLE INFO

*Article history:*
Received 11 June 2015
Received in revised form
21 April 2016
Accepted 21 April 2016

*Keywords:*
Cognitive ability
Cognitive styles
Training experience
Human performance

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.

* Corresponding author.
*E-mail addresses:* pand10@mails.tsinghua.edu.cn (D. Pan), ldlzyj@163.com (Y. Zhang), zzli@tsinghua.edu.cn (Z. Li).
[1] Postal address: South 524E, Shunde Building, Tsinghua University, PR China.
[2] Postal address: South 526, Shunde Building, Tsinghua University, PR China.

http://dx.doi.org/10.1016/j.ergon.2016.04.008
0169-8141/

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

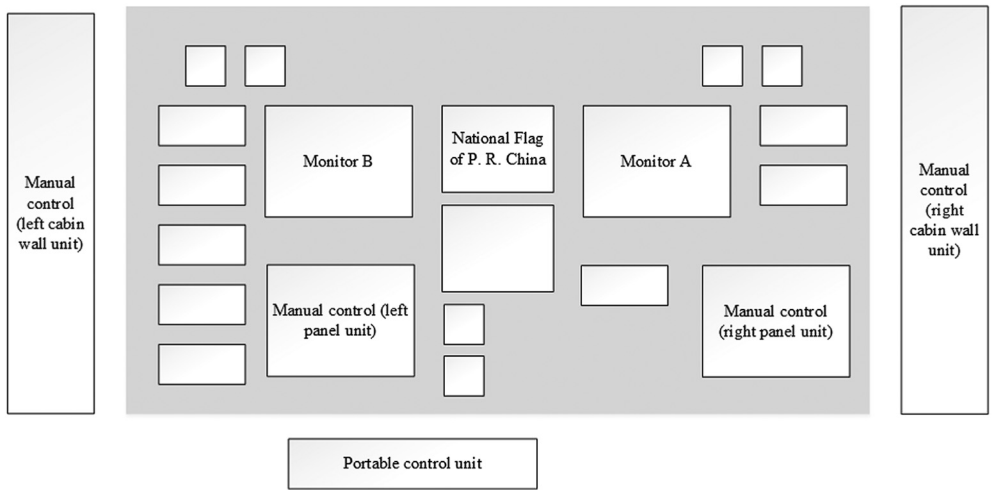



**Fig. 1.** Illustration of the experimental platform.

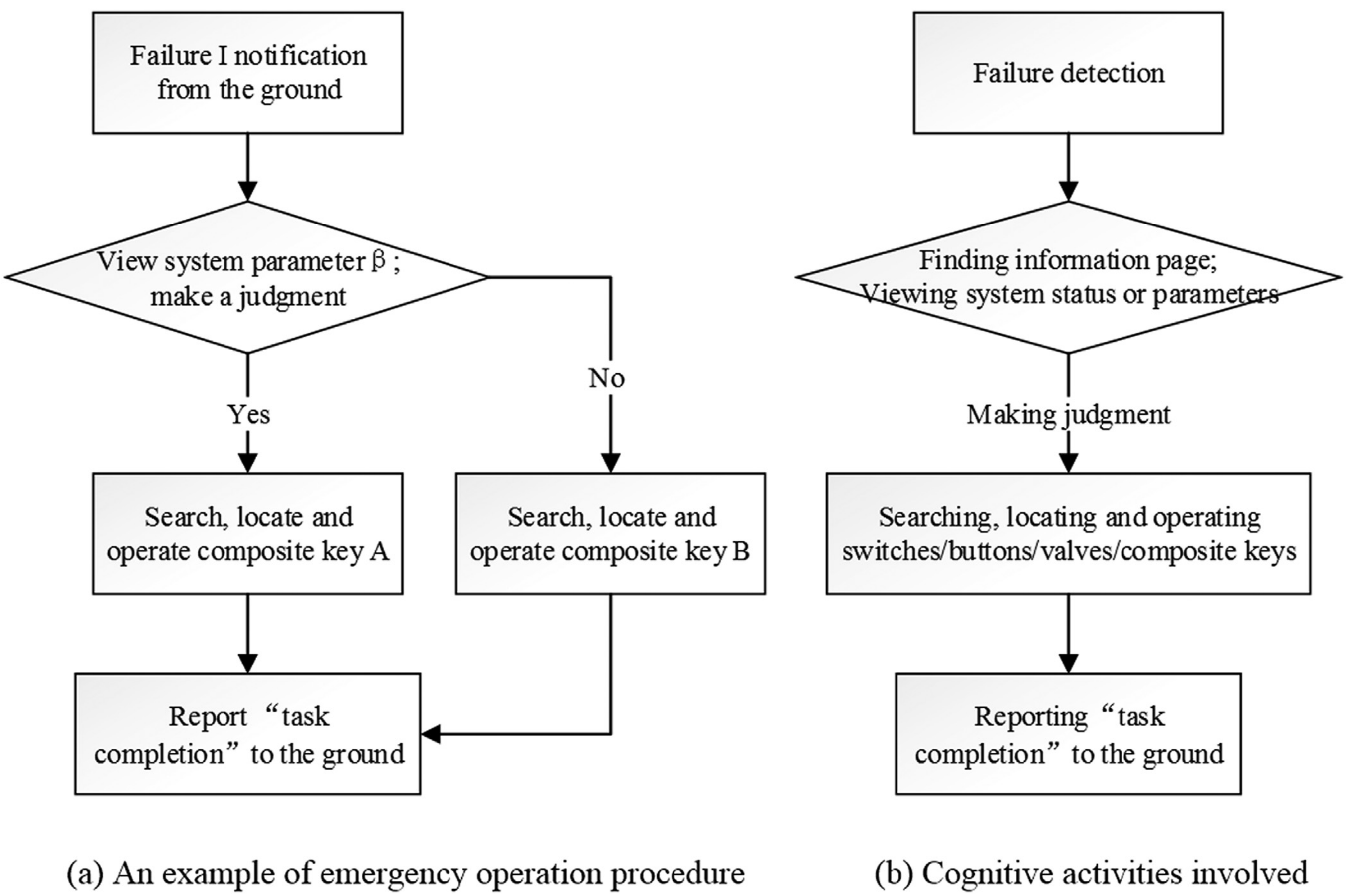



**Fig. 2.** Schematic diagram of experimental task.

formal experiment, a pilot study was conducted to verify the rationality of the experiment process and the reliability of the experimental platform. Two volunteers were recruited from China astronaut centre. They were asked to go through every single step of the formal experiment. Then, a week before the formal experiment, each participant read the experiment introduction and signed a consent form. Training for the participants and experimenters and testing of the participants' characteristics were also conducted. During the formal experiment, there were three training phases, namely, initial training, repeated training, and training examination. At each training phase, the participants had to finish all nine emergency operations thrice. The time interval among these three training phases was one week. The experimental procedure was approved by an institutional review board.

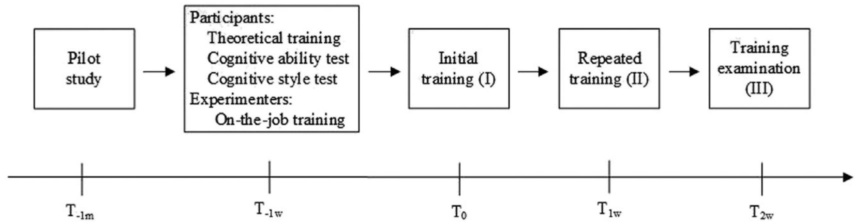



**Fig. 3.** Experimental procedure. ($T_{-1m}$: one month before phase I; $T_{-1w}$: one week before phase I; $T_{1w}$: one week after phase I; $T_{2w}$: two weeks after phase I).

## 2.5. Independent variables

### 2.5.1. Cognitive ability

Cognitive ability refers to the ability of a human brain to extract, process, and store information, which is the basis of learning, thinking, inferring, and knowing the world for an individual (Jonassen and Grabowski, 1993). For a spaceflight mission, different aspects of cognitive ability are required. First, information seeking ability is required to find the involved system status or parameters. Second, inference ability is needed to make judgments and develop hypotheses about system failure. It has been found that reasoning and perceptual ability of aircraft pilots are significantly correlated with different levels of flight performance (Boehm-Davis et al., 1997). Third, an instrument board operator requires spatial ability in order to form a virtual map of instrument board with different kinds of switches, buttons, valves and composite keys. It has been found that spatial ability is positively correlated with navigation performance (Rodes and Gugerty, 2012), visual performance (Chen and Terrence, 2008; Chen, 2010; Chen and Barnes, 2012), and manual rendezvous and docking performance (Liu et al., 2013; Wang et al., 2014). Roger et al. (2009) indicated that users' spatial abilities should be taken into account when designing a pedestrian navigation assistance system. At last, attention is a kind of cognitive resource (Posner and Petersen, 1989) and is required for all kinds of task. The ability of attention control and allocation affects multi-tasking performance (Goonetilleke and Luximon, 2010; Chen and Barnes, 2012). In a word, cognitive ability can be considered as one of the best predictors of different types of task performance (Hunter and Hunter, 1984; Schmidt and Hunter, 1998; Schmidt, 2002).

As shown in Fig. 2 (b), the main cognitive activities involved in our experimental tasks included detecting failure, finding display pages of system information, viewing system status or parameters, making judgments, and searching, locating and operating switches/buttons/valves/composite keys. According to these cognitive activities, information seeking ability, inference ability, spatial recognition ability, attention span, and attention allocation ability were identified to be possibly influencing the task process. These five cognitive abilities were measured using DXC-W. The DXC-W was developed by the Fourth Military Medical University in China based on the US Air Force Officer Qualifying Test (AFOQT; Carretta and Ree, 1996), US Army Aviation Selection Test, US Air Force Basic Attributes Testing System (BAT; Carretta, 1987), European Space Agency Selection Test, Psychological Test of Russian Gagarin Training Centre, and the Chinese Air Force Pilot Selection Test. It includes 32 tests of cognitive abilities and 22 tests of personality traits. This instrument could be a generalized tool to measure basic cognitive abilities (Luo and Hu, 2006) and was used in several studies such as Zhang et al. (2009) and Liu et al. (2008).

In this study, the test of digit search (Zhang et al., 2009; Liu et al., 2008) was used to assess information seeking ability. The test of rule finding (Luo and Hu, 2006; Zhang et al., 2009) was used to assess inference ability. The test of comparing simulated scales (Luo and Hu, 2006; Liu et al., 2008; Zhang et al., 2009) was used to test spatial recognition ability. Attention span (Liu et al., 2008) and the multi-tasking attention allocation ability were also tested. The details about these cognitive ability tests are described in Table 1. The cognitive test scores were determined by accuracy and time spent, i.e., the higher the accuracy in unit time is, the higher the cognitive test score is. Overall score of cognitive ability is defined as the mean of these five sub-scales.

### 2.5.2. Cognitive style

Cognitive style refers to an individual's preferred unique pattern to perceive and process information (such as collect and organize, analyse and evaluate, think and understand, memory and represent information), make decision and solve problem (Kogan, 1973; Witkin et al., 1977; Messick, 1984; Tennant, 1988; Hunt et al., 1989; Riding and Cheema, 1991; Jonassen and Grabowski, 1993; van Den Broeck et al., 2003). In the present study, cognitive style was tested by the Felder-Soloman Index of Learning Styles (ILS). Felder and Spurlin (2005) reviewed several published analyses and suggested that this instrument might be reliable, valid and suitable. This test consists of 44 questions and assesses cognitive style from four dimensions, which are active-reflective, sensing-intuitive, visual-verbal and sequential-global. Each dimension is associated with 11 items. Each item has two options (a or b). Using sequential-global as an example, the score is obtained from the number of ‘a’ responses subtracted from the number of ‘b’ responses. The result is an odd number between $-11$ and $+11$. A negative score indicates that the individual is an individual with sequential cognitive style. Otherwise, he/she is with global cognitive style. Furthermore, the absolute value of the score indicates the extent of being sequential or global.

### 2.5.3. Training experience

Training experience had three levels and was defined as 0–2. At the initial phase, the training experience was defined as 0. At the repeated phase, it was defined as 1. At the examination phase, it was defined as 2.

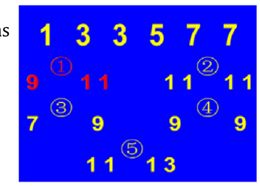
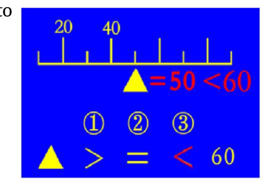
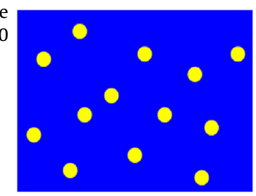
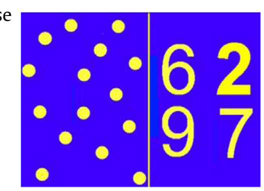
## 2.6. Dependent variables

Dependent variables included how long a participant took to accomplish all nine emergency operations in terms of completion time, and the number of errors that a participant made during the nine operations. Less time or fewer errors indicates better human performance.

## 2.7. Data analysis

Correlation analysis was carried out in the present study since the independent variables (cognitive ability and cognitive style) were measured with continuous scores using the testing instruments. The reason that we did not divide the participants into different groups for running ANOVA, non-parametric Friedman, or

**Table 1**
Tests of cognitive ability.

| Cognitive abilities | Tests | Examples |
|---|---|---|
| Information seeking | Digit search: Display 9 numbers from 0 to 9 randomly on the screen every time, please quickly find out which one is not included and click the corresponding number key as soon as possible on the premise of guarantee correct. 30 questions are included in total. |   |
| Inference | Rule finding: Display a Sequence of Number and 5 pairs of Numbers, please quickly find out the permutation law of the sequence, and choose a pair of Numbers to fill in the blank after the sequence and click the corresponding number key as soon as possible on the premise of guarantee correct. 26 questions are included in total. |   |
| Spatial recognition | Comparing simulated scales: Two Numbers will be marked on a graduated scale, please according to these Two Numbers to decide what Number the triangle stands for. Then compare the Triangle Number with the Target Value. If Triangle Number > Target Value, click 1, if Triangle Number = Target Value, click 2, Triangle Number < Target Value, click 3. 30 questions are included in total. |   |
| Attention span | Display 6 to 15 light spots on the screen every time. Please count the number of these light spots quickly. According to the Units Digit of the number, click the corresponding number key as soon as possible on the premise of guarantee correct. 30 questions are included in total. |  |
| Attention allocation | Display 4 numbers on the screen every time. Please add them up. At the same time, some light spots will come out. Please count the number of these light spots quickly. Finally, add the sum of those 4 numbers to the number of light spots. According to the Units Digit of the answers, click the corresponding number key as soon as possible on the premise of guarantee correct. 30 questions are included in total. |   |

Chi-square test was because of the limited sample size (N = 28). In particular, the balance of sample size between groups could not be well controlled (as reflected in Table 2) since the participants were randomly recruited. Furthermore, stepwise linear regression analysis was used to examine the predictive capability of cognitive ability and cognitive style on operation performance for each training phase using a statistical significance at 0.05 level. At last, hierarchical linear model was conducted to examine the interaction between cognitive characteristics and training experience.

**Table 2**
Results of the cognitive style tests.

| Cognitive style | | Sample size |
|---|---|---|
| Active vs. Reflective | Active | 6 |
| | Reflective | 22 |
| Sensing vs. Intuitive | Sensing | 15 |
| | Intuitive | 13 |
| Visual vs. Verbal | Visual | 21 |
| | Verbal | 7 |
| Sequential vs. Global | Sequential | 7 |
| | Global | 21 |

## 3. Results

One outlier was found when checking the collected data. The number of error the participant #3 made in the initial training (i.e., 18.33) was more than six times of the average (2.75). Thus, the performance data (including completion time and number of error) of the participant #3 in the initial training phase was removed. All results below were based on the data analysis after excluding the outlier.

### 3.1. Correlations between individual characteristics and operation performance

The descriptive statistics of all independent and dependent variables are shown in Table 3. The average task completion time of a participant ranged from 290.11 to 883.74 (mean: 504.43; SD: 117.96) and the average number of human error ranged from 0 to 9.83 (mean: 2.55; SD: 2.20). Cognitive ability (overall score) ranged from 4.26 to 8.50 (mean: 6.57; SD: 1.12). Specifically, information seeking ability ranged from 1.00 to 9.00 (mean: 5.86; SD: 2.31), inference ability from 3.00 to 9.00 (mean: 7.51; SD: 1.78), spatial recognition from 4.10 to 9.00 (mean: 6.52; SD: 1.44), attention span from 6.40 to 9.00 (mean: 8.75; SD: 0.68) and attention allocation

**Table 3**
Descriptive statistics.

| | N | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Completion Time (s) | 80 | 504.43 | 117.96 | 290.11 | 883.74 |
| Errors (#) | 80 | 2.55 | 2.20 | 0 | 9.83 |
| Cognitive ability | | | | | |
| Information seeking ability (1–9) | 27 | 5.86 | 2.31 | 1.00 | 9.00 |
| Inference ability (1–9) | 27 | 7.51 | 1.78 | 3.00 | 9.00 |
| Spatial recognition (1–9) | 27 | 6.52 | 1.44 | 4.10 | 9.00 |
| Attention span (1–9) | 27 | 8.75 | 0.68 | 6.40 | 9.00 |
| Attention allocation ability (1–9) | 27 | 4.19 | 1.54 | 1.40 | 7.90 |
| Overall score | 27 | 6.57 | 1.12 | 4.26 | 8.50 |
| Cognitive styles | | | | | |
| Active-Reflective (−11 to +11) | 27 | 2.56 | 3.57 | −7 | 7 |
| Sensing-Intuitive (−11 to +11) | 27 | −0.44 | 4.34 | −7 | 7 |
| Visual-Verbal (−11 to +11) | 27 | −3.67 | 4.61 | −11 | 7 |
| Sequential-Global (−11 to +11) | 27 | 2.04 | 3.52 | −5 | 9 |

ability from 1.40 to 7.90 (mean: 4.19; SD: 1.54). As to cognitive style, the score on Active-Reflective dimension ranged from −7 to 7 (mean: 2.56; SD: 3.57), Sensing-Intuitive from −7 to 7 (mean: −0.44; SD: 4.34), Visual-Verbal from −11 to 7 (mean: −3.67; SD: 4.61), and sequential-Global from −5 to 9 (mean: 2.04; SD: 3.52).

### 3.1.1. Cognitive ability

As shown in Table 4, the overall score of cognitive ability was significantly correlated with task completion time ($r_s = -0.276$, $p = 0.013$). That is, individuals with a high overall score spent less time than participants with a low overall score. No significant relationship was found between overall score and number of errors ($r_s = -0.183$, $p = 0.105$).

Examination of the sub-scales of cognitive ability (see Table 5) showed that in particular, sub-scales 'inference ability', 'spatial recognition' and 'attention span' explained the significant correlations between overall cognitive ability and task completion time. The participants with high inference ability, spatial recognition or attention span spent less time than those with low inference ability ($r_s = -0.262$, $p = 0.019$), spatial recognition ($r_s = -0.356$, $p = 0.001$) or attention span ($r_s = -0.227$, $p = 0.043$). Additionally, the significant correlation between attention allocation ability and number of error was found ($r_s = -0.267$, $p = 0.017$).

### 3.1.2. Cognitive style

As shown in Table 4, no significant correlations were found between the first three dimensions of cognitive style (active-reflective, sensing-intuitive, visual-verbal) and performance. Sequential-global cognitive styles was significantly correlated with the number of errors ($r_s = 0.264$, $p = 0.018$). The participants with a low score of sequential-global made fewer errors than those with a high score of sequential-global. That is, the participants with sequential cognitive style made fewer errors than those with global cognitive style. There was no significant relationship between sequential-global cognitive style and completion time ($r_s = 0.184$, $p = 0.102$).

### 3.1.3. Training experience

Training experience was significantly correlated with task completion time ($r_s = -0.672$, $p < 0.001$), but not with the number of errors ($r_s = -0.182$, $p = 0.106$) (see Table 4). That is, training can significantly increase the operation speed but cannot decrease the number of errors.

## 3.2. Performance prediction model

Stepwise linear regression analysis was conducted to establish a model to predict task completion time with the overall score of cognitive ability and cognitive style as predictors for each of the three training phases. As shown in Table 6, at the initial training when the participants had little experience, overall score of cognitive ability was a significant predictor of task completion time ($p = 0.012$) and accounted for 23.6% of the variance. At the examination phase, when the participants had more experience after being trained twice, sequential-global cognitive style was a significant predictor of task completion time ($p = 0.031$) and accounted for 17.3% of the variance.

Similar regression analysis was performed for the number of errors. As shown in Table 6, at the repeated training, sequential-global cognitive style was a significant predictor of the number of errors ($p = 0.048$) and accounted for 14.7% of the variance in number of errors.

Since the collinear independent variables were ruled out in the stepwise linear regression analysis, there were no significant intercorrelations among our performance predictive variables.

## 3.3. Effect of individual characteristics on the influence of training experience on performance

A two-level hierarchical linear model was conducted to examine the effect of individual characteristics on the influence of training experience on performance. The model is the following:

$$\text{Level 1 model}: \quad Y = \pi_0 + \pi_1 \cdot \text{Exp.} + e$$

$$\text{Level 2 model}: \quad \pi_0 = \beta_{00} + r_0$$
$$\pi_1 = \beta_{10} + \beta_{11} \cdot L_1 + \beta_{12} \cdot L_2 + \beta_{13} \cdot L_3 + \beta_{14} \cdot L_4 + \beta_{15} \cdot CA + r_1$$

Note: Exp.—Training experience; $L_1$—Active-reflective; $L_2$—Sensing-intuitive; $L_3$—Visual-verbal; $L_4$—Sequential-global; CA—overall score of cognitive ability.

where Y is the performance in terms of completion time or number of errors; $\beta_{00}$ is the general intercept; $\beta_{10}$ is the regression coefficient of the first level variable, namely, training experience; $\beta_{11} \sim \beta_{15}$ are regression coefficients of the effect of individual characteristics on the influence of training experience on performance (cross-level interaction); $e$ is the error term on the first level; and $r_0$ and $r_1$ are the error terms on the second level.

The results are shown in Table 7. The sequential-global score significantly decreased the influence of training experience on task completion time ($\beta_{10} = -100.11$, $p < 0.001$; $\beta_{14} = 2.62$, $p = 0.022$). As shown in Fig. 4, compared to individuals with global cognitive style (i.e., high sequential-global score), the influence of training

**Table 4**
Pearson correlations between individual characteristics and performance.

| Performance measure | Overall score of cognitive ability | Active-Reflective | Sensing-Intuitive | Visual-Verbal | Sequential-Global | Training experience |
|---|---|---|---|---|---|---|
| Completion time | −0.276* | −0.116 | 0.015 | −0.180 | 0.184 | −0.672** |
| Number of errors | −0.183 | −0.117 | 0.072 | −0.077 | 0.264* | −0.182 |

*$p < 0.05$.
**$p < 0.01$ (two-tailed).

**Table 5**
Pearson correlations between sub-scales of cognitive ability and performance.

| Performance measure | Information seeking | Inference ability | Spatial recognition | Attention span | Attention allocation |
|---|---|---|---|---|---|
| Completion time | −0.102 | −0.262* | −0.356** | −0.227* | −0.111 |
| Number of errors | −0.060 | −0.075 | −0.186 | −0.105 | −0.267* |

*$p < 0.05$.
**$p < 0.01$ (two-tailed).

**Table 6**
Results of stepwise linear regression analysis.

| Training phase | Task completion time | | | | | Number of errors | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Predictors+ | B | β | $p$ | $R^2$ | Predictors+ | B | β | $p$ | $R^2$ |
| I | Overall cognitive ability | −42.42 | −0.49 | 0.012 | 23.6% | None | | | | |
| II | None | | | | | Sequential-Global | 0.26 | 0.38 | 0.048 | 14.7% |
| III | Sequential-Global | 7.66 | 0.42 | 0.031 | 17.3% | None | | | | |

+ Only the significant predictors are listed.

**Table 7**
Hierarchical linear model results.

| Coefficients | Performance measures | |
|---|---|---|
| | Completion time | Number of errors |
| $\beta_{00}$ | 506.62** | 2.539** |
| $\beta_{10}$ | −100.11** | −0.468* |
| $\beta_{11}$ | 0.58 | −0.039 |
| $\beta_{12}$ | 0.71 | −0.082 |
| $\beta_{13}$ | 1.35 | 0.003 |
| $\beta_{14}$ | 2.62* | −0.052 |
| $\beta_{15}$ | 1.69 | −0.066 |

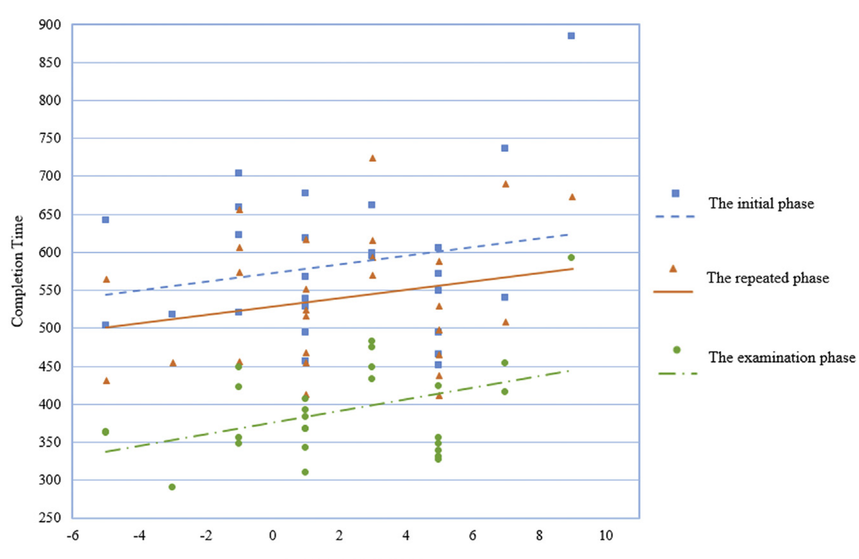



**Fig. 4.** The interaction effect of training experience and Sequential-Global cognitive style on task completion time.

experience on task completion time was greater for those with sequential cognitive style (i.e., low sequential-global score).

## 4. Discussion

Researchers have previously found that work performance was strongly correlated with cognitive ability in different work situations (Schmidt and Hunter, 1998; Schmidt, 2002). The first major finding in the present study is that for spaceflight emergency operations on the instrument board, overall cognitive ability (specifically inference ability, spatial recognition, and attention span) was significantly correlated with task completion time, whereas attention allocation ability and cognitive styles (specifically sequential-global) were significantly correlated with the number of human errors. The participants with high cognitive ability spent less time than those with low cognitive ability, and those with high attention allocation ability made fewer errors. This result indicates that when performing tasks with high time pressure, the inference ability, spatial recognition, attention span and attention allocation of astronauts are critical to system safety. Thus, these four types of cognitive abilities should be emphasized when selecting and training astronauts.

As to cognitive style, individuals with sequential cognitive style prefer "left-brain" thinking, makes judgement based on mental reasoning, and focuses on details, whereas those with global cognitive style prefer "right-brain" thinking, makes judgement based on feelings, and absorbs information with a global perspective (Sadler-Smith, 1999; Felder and Spurlin, 2005). The cognitive activities involved in the experimental task included detecting failure, finding information pages, viewing parameters, making judgments, searching, locating and operating switches/buttons/valves/composite keys and so on. Meanwhile, these cognitive activities were performed step by step based on the paper-based operation procedures (see Fig. 2(a)). Therefore, the finding that the participants with sequential cognitive style made fewer errors than those with global cognitive style in spaceflight instrument operations is reasonable. This result suggests that operators with sequential cognitive style might be more appropriate for spaceflight instrument operations. Meanwhile, the participants with sequential cognitive style learnt faster than those with global cognitive style in spaceflight instrument operations (See Fig. 4). Moreover, Tracey et al. (2007) found that the effect of cognitive ability on work performance is large, particularly for novices. A similar effect was observed in the present study. When the participants had little experience (at the initial phase), overall score of cognitive ability was a good predictor for completion time of spaceflight emergency operations and can account for 23.6% of the variance. However, with the increase of experience, overall score of cognitive ability was no longer a predictor for completion time. This conforms to the convergence theory about performance in Ackerman (1987), which means that those abilities involved were environmentally determined and all participants could perform at similar levels with sufficient task practice. However, even with the increase of practice, the sequential-global cognitive style was a good predictor of the number of errors (at the repeat phase) accounting for 14.7% of the variance, and also a good predictor of task completion time (at the examination phase) accounting for 17.3% of the variance. This result indicates that cognitive styles should be more emphasized than cognitive ability in astronaut selection. Astronauts are well trained before real space missions. After well-trained, cognitive ability may be no longer a significant factor affecting their performance. However, this does not work for the influence of cognitive style. Cognitive style is an individual's preferred unique pattern to perceive and process information, make decision and solve problem (Jonassen and Grabowski, 1993). It is relatively more stable for an individual when compared with cognitive ability. Individuals' cognitive style is difficult to be changed by training. It can be believed that the effect of cognitive style on performance may be lasted, even becomes relatively more significant after the effect of cognitive ability on performance disappeared, despite the variance of human error explained by cognitive style was small (14.7%) since many other factors can cause human error (Reason, 1990). Therefore, we can recommend that attention should be given to individuals' cognitive style during astronaut selection and the effectiveness of training programs for operators with different cognitive styles.

Humans are flexible. Certain human potentials can be developed and reinforced through proper training. Training is a systematic approach for an individual or team to acquire knowledge and skills and improve performance (Patrick, 1992; Aguinis and Kraiger, 2009). The present study shows that training can significantly decrease task completion time. Training produced better performance. Furthermore, the score of sequential-global cognitive style decreased the effect of training experience on completion time. This result indicates that training can improve the task completion time of those with sequential cognitive style more significantly than those with global cognitive style.

The major limitation of this study was the use of student participants because real operators or astronauts were difficult to recruit. In order to decrease the difference between the participants and astronauts and improve the reliability and validity of our experiment results, the participants were selected through rigorous screening. As described in Section 2.1, they were all right-handed, studying aeronautical and astronautical engineering, aged from 20 to 26, and 165 cm–175 cm tall, to ensure that they were homogeneous and had an understanding and knowledge of spaceflight systems, and in a certain extent to make them conform to the selection criteria of future astronauts such as load expert and spacecraft engineer. Anyway, the participants could still somewhat different from real astronauts. This should be considered in the use of the findings from this study.

## 5. Conclusions

In this study, the effects of cognitive ability, cognitive style and training on human performance of spaceflight emergency operations were examined. It was found that inference ability, spatial recognition ability, and attention span significantly reduced task completion time, while attention allocation ability and sequential-global cognitive style significantly influenced the number of error. Meanwhile, training experience significantly reduced task completion time. Furthermore, the interaction between cognitive ability/sequential-global cognitive style and training was significantly emerged when cognitive ability and cognitive style were used to predict human performance. The above findings would improve the understanding of determinants of human performance and help update operator selection and training strategies for complex, high-risk work environments.

## Acknowledgements

This study was supported by the National Natural Science Foundation of China (Project No. 71371174).

## References

Ackerman, P.L., 1987. Individual differences in skill learning: an integration of psychometric and information processing perspectives. Psychol. Bull. 102 (1), 3.
Ackerman, P.L., 2007. New developments in understanding skilled performance. Curr. Dir. Psychol. Sci. 16 (5), 235–239.
Aguinis, H., Kraiger, K., 2009. Benefits of training and development for individuals and teams, organizations, and society. Annu. Rev. Psychol. 60, 451–474.
Boehm-Davis, D.A., Robert, W.H., Hansberger, J., 1997. Pilot abilities and performance. In: Proceedings of the Ninth International Symposium on Aviation Psychology. Ohio State University, OH, Columbus.
Burkolter, D., Kluge, A., Brand, M., Ritzmann, S., Sauer, J., 2009a. Cognitive and personality variables of operators: individual characteristics and process control performance. In: de Waard, D., Godtheip, J., Kooi, F.L., Brookhuis, K.A. (Eds.), Human Factors, Security and Safety. Shaker Publishing, Maastricht, the Netherlands, pp. 77–88.
Burkolter, D., Kluge, A., Sauer, J., Ritzmann, S., 2009b. The predictive qualities of operator characteristics for process control performance: the influence of personality and cognitive variables. Ergonomics 52 (3), 302–311.
Carretta, T.R., 1987. Basic Attributes Tests (BAT) System: Development of an Automated Test Battery for Pilot Selection (No. AFHRL-TR-87–9). Air Force Human Resources Lab Brooks, AFB TX.
Carretta, T.R., Ree, M.J., 1996. Factor structure of the air Force Officer Qualifying test: analysis and comparison. Mil. Psychol. 8 (1), 29.
Cassidy, S., 2004. Learning styles: an overview of theories, models, and measures. Educ. Psychol. 24 (4), 419–444.
Chen, J.Y., 2010. UAV-guided navigation for ground robot teleoperation in a military reconnaissance environment. Ergonomics 53 (8), 940–950.
Chen, J.Y., Barnes, M.J., 2012. Supervisory control of multiple robots: effects of imperfect automation and individual differences. Hum. Factors 54 (2), 157–174.
Chen, J.Y.C., Terrence, P.I., 2008. Effects of tactile cueing on concurrent performance of military and robotics tasks in a simulated multitasking environment. Ergonomics 51 (8), 1137–1152.
Collins, D.L., 1985. Psychological Issues Relevant to Astronaut Selection for Long-duration Space Flight: a Review of the Literature (No. AFHRL-TP-84–41). Air Force Human Resources LAB Brooks, AFB TX.
van Den Broeck, H., Vanderheyden, K., Cools, E., 2003. Individual Differences in Cognitive Styles: Development, Validation and Cross Validation of the Cognitive Style Inventory. 27. Vlerick Leuven Gent Management School.
Dion, K.L., 2004. Interpersonal and group processes in long-term spaceflight crews: perspectives from social and organizational psychology. Aviat. space, Environ. Med. 75 (Suppl. l), C36–C43.
Dong, Y., Zhou, R., Guo, X., 2008. An experimental research on prospective memory in children with learning disabilities. Chin. J. Special Educ. 97, 68–74.
Dunn, R., Beaudry, J.S., Klavas, A., 2002. Survey of research on learning styles. Calif. J.

Sci. Educ. 2 (2), 75–98.
Felder, R.M., Silverman, L.K., 1988. Learning and teaching styles in engineering education. Eng. Educ. 78 (7), 674–681.
Felder, R.M., Spurlin, J., 2005. Applications, reliability and validity of the index of learning styles. Int. J. Eng. Educ. 21 (1), 103–112.
Goonetilleke, R.S., Luximon, Y., 2010. The relationship between monochronicity, polychronicity and individual characteristics. Behav. Inf. Technol. 29 (2), 187–198.
Hariri, N., Asadi, M., Nooshinfard, F., 2014. Analysis of researchers' information searching behaviour based on verbal/imagery cognitive styles on web. Iran. J. Inf. Process. Manag. 29 (4), 1007–1036.
Henderson, N.D., 2010. Predicting long-term firefighter performance from cognitive and physical ability measures. Pers. Psychol. 63 (4), 999–1039.
Hollnagel, E., 1998. Cognitive Reliability and Error Analysis Method (CREAM). Elsevier Science Ltd, New York.
Hough, L.M., Furnham, A., 2003. Use of personality variables in work settings. In: Borman, W.C., Ilgen, D.R., Klimoski, R.J. (Eds.), Handbook of Psychology, 12. John Wiley & Sons, Inc., Hoboken, New Jersey, pp. 131–170.
Hunt, R.G., Krzystofiak, F.J., Meindl, J.R., Yousry, A.M., 1989. Cognitive style and decision making. Org. Behav. Human Decis. Process. 44, 436–453.
Hunter, J.E., Hunter, R.F., 1984. Validity and utility of alternative predictors of job performance. Psychol. Bull. 96 (1), 72–98.
Jonassen, D.H., Grabowski, B.L., 1993. Handbook of Individual Differences, Learning, and Instruction. Lawrence Erlbaum Associates, Publishers, Hillsdale, New Jersey.
Kanas, N., Sandal, G., Boyd, J.E., Gushin, V.I., Manzey, D., North, R., et al., 2009. Psychology and culture during long-duration space missions. Acta Astronaut. 64 (7), 659–677.
Katz, N., 1990. Problem solving and time: functions of learning style and teaching methods. OTJR Occup. Particip. Health 10 (4), 221–236.
Kogan, N., 1973. Creativity and cognitive style: a life-span perspective. Life-span Dev. Psychol. Personal. Soc. 145–178.
Kolb, D.A., 2014. Experiential learning: experience as the source of learning and development. FT Press, Pearson Education, Inc., Upper Saddle River, New Jersey.
Komarraju, M., Karau, S.J., Schmeck, R.R., Avdic, A., 2011. The big five personality traits, learning styles, and academic achievement. Personal. Individ. Differ. 51 (4), 472–477.
Li, Z., 2011. Fault tree analysis of train crash accident and discussion on safety of complex systems. Ind. Eng. Manag. 16 (4), 1–8. In Chinese.
Liu, X., Bai, Y., Liu, F., Wang, J., Jing, X., Qin, H., Wu, B., 2008. Research on the mental psycho-effects and their countermeasures of sleep deprivation and society isolation for 72 hours. Space Med. Med. Eng. 2008 21 (3), 257–261.
Liu, A.M., Oman, C.M., Galvan, R., Natapoff, A., 2013. Predicting space telerobotic operator training performance from human spatial ability assessment. Acta Astronaut. 92 (1), 38–47.
Luo, M., Hu, W., 2006. The preparatory research to constructing new items of basic ability tests on subsystem I of cadet candidate. Chin. J. Aerosp. Med. 17 (4), 264–268.
Manzey, D., Schiewe, A., 1992. Psychological training of German science astronauts. Acta astronaut. 27, 147–154.
Manzey, D., Schiewe, A., Fassbender, C., 1995. Psychological countermeasures for extended manned spaceflights. Acta Astronaut. 35 (4), 339–361.
Messick, S., 1984. The nature of cognitive styles: problems and promise in educational practice. Educ. Psychol. 19 (2), 59–74.
Morphew, M.E., 2001. Psychological and human factors in long duration spaceflight. McGill J. Med. 6 (1), 74–80.
Musson, D.M., Helmreich, R.L., 2005. Long-term personality data collection in support of spaceflight and analogue research. Aviat. Space. Environ. Med. 76 (Suppl. 1), B119–B125.
Musson, D.M., Sandal, G., Helmreich, R.L., 2004. Personality characteristics and trait clusters in final stage astronaut selection. Aviat. Space. Environ. Med. 75 (4), 342–349.
Nelson, W.R., 1999. Applying Lessons Learned to Enhance Human Performance and Reduce Human Error for ISS Operations. In: Space Technology and Applications International Forum-1999, 458. AIP Publishing, pp. 420–425, 1.
Ovaskainen, H., Heikkilä, M., 2007. Visuospatial cognitive abilities in cut-to-length single-grip timber harvester work. Int. J. Ind. Ergon. 37 (9), 771–780.
Patrick, J., 1992. Training: Research and Practice. Academic Press, San Diego, CA, US.
Poropat, A.E., 2009. A meta-analysis of the five-factor model of personality and academic performance. Psychol. Bull. 135 (2), 322.
Posner, M.I., Petersen, S.E., 1989. The Attention System of the Human Brain (No. TR-89-1). Washington University, Department of Neurology.
Rau, P.L.P., Choong, Y.Y., Salvendy, G., 2004. A cross cultural study on knowledge representation and structure in human computer interfaces. Int. J. Ind. Ergon. 34 (2), 117–129.
Reason, J., 1990. Human Error. Cambridge University Press, New York.
Recker, J., Reijers, H.A., van de Wouw, S.G., 2014. Process model comprehension: the effects of cognitive abilities, learning style, and strategy. Commun. Assoc. Inf. Syst. 34, 199–222.
Riding, R., Cheema, I., 1991. Cognitive styles — an overview and integration. Educ. Psychol. 11 (3–4), 193–215.
Rodes, W., Gugerty, L., 2012. Effects of electronic map displays and individual differences in ability on navigation performance. Hum. Factors 54 (4), 589–599.
Roger, M., Bonnardel, N., Le Bigot, L., 2009. Improving navigation messages for mobile urban guides: effects of the guide's interlocutor model, spatial abilities and use of landmarks on route description. Int. J. Ind. Ergon. 39 (3), 509–515.
Sadler-Smith, E., 1999. Intuition-analysis cognitive style and learning preferences of business and management students: a UK exploratory study. J. Manag. Psychol. 14 (1), 26–39.
Schmidt, F.L., 2002. The role of general cognitive ability and job performance: why there cannot be a debate. Hum. Perform. 15 (1–2), 187–210.
Schmidt, F.L., Hunter, J.E., 1998. The validity and utility of selection methods in personnel psychology: practical and theoretical implications of 85 years of research findings. Psychol. Bull. 124 (2), 262–274.
Seastrom, J.W., Peercy, R.L., Johnson, G.W., Sotnikov, B.J., Brukhanov, N., 2004. Risk management in international manned space program operations. Acta astronaut. 54 (4), 273–279.
Sprehn, K.A., Kremer, G.E.O., Riley, D.R., 2013. Information Format and Cognitive Style the Impact of Paired Styles on Performance and Preference. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 57. SAGE Publications, pp. 1129–1133, 1.
Tennant, M., 1988. Psychology and Adult Learning. Routledge, London.
Thatcher, A., 2006. Information-seeking behaviours and cognitive search strategies in different search tasks on the WWW. Int. J. Ind. Ergon. 36 (12), 1055–1068.
Torenvliet, G.L., Jamieson, G.A., Vicente, K.J., 2000. Making the most of ecological interface design: the role of individual differences. Appl. Ergon. 31, 395–408.
Tracey, J.B., Sturman, M.C., Tews, M.J., 2007. Ability versus personality factors that predict employee job performance. Cornell Hotel Restaur. Adm. Q. 48 (3), 313–322.
Wang, C., Tian, Y., Chen, S., Tian, Z., Jiang, T., Du, F., 2014. Predicting performance in manually controlled rendezvous and docking through spatial abilities. Adv. Space Res. 53 (2), 362–369.
Witkin, H.A., Moore, C.A., Goodenough, D.R., Cox, P.W., 1977. Field dependent and field independent cognitive styles and their educational implications. Rev. Educ. Res. 47, 1–64.
Zhang, Y., Liu, X., Li, Z., Wu, B., Liu, F., Jing, X., Wang, J., Qin, H., Wu, S., 2009. Combined effects of sleep deprivation, narrow space, social isolation and high cognitive workload on cognitive ability of Chinese operators. In: Schmorrow, D.D., et al. (Eds.), Augmented Cognition, HCII2009, LNAI5638. Springer, Berlin, pp. 311–316.
Zhang, Y., Wu, B., Zhang, X., Wang, Q., Liu, M., 2011. Task complexity related training effects on operation error of spaceflight emergency task. In: Duffy, V.G. (Ed.), Digital Human Modeling, HCII2011, LNCS 6777. Springer, Berlin, pp. 436–445.
Zhang, J., Li, Y., Wu, C., 2013. The influence of individual and team cognitive ability on operators' task and safety performance: a multilevel field study in nuclear power plants. PloS one 8 (12), e84528.