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Predicting performance in manually controlled rendezvous and docking through spatial abilities

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Abstract

Manually controlled rendezvous and docking (manual RVD) is a challenging space task for astronauts. This study aims to identify spatial abilities that are critical for accomplishing manual RVD. Based on task analysis, spatial abilities were deduced to be critical for accomplishing manual RVD. 15 Male participants performed manual RVD task simulations and spatial ability tests (the object-manipulation spatial ability and spatial orientation ability). Participants' performance in the test of visualization of viewpoints (which measures the spatial orientation ability) was found to be significantly correlated with their manual RVD performance, indicating that the spatial orientation ability in the sense of perspective taking is particularly important for accomplishing manual RVD.

Keywords: Manually controlled rendezvous and docking; Spatial ability; Object-manipulation; Spatial orientation; Perspective taking

1. Introduction

Astronauts are exposed to numerous stressors during spaceflights, such as microgravity, confinement and radiation, all of which may impair human cognitive capabilities (Geuna and Brunelli, 1995). The human research roadmap published by the National Aeronautics and Space Administration (NASA) lists "Mismatch between Crew Cognitive Capabilities and Task Demands" as a major risk that astronauts may encounter in space (NASA Johnson Space Center, 2001). If tasks prove too difficult for human cognitive capabilities, whether as a result of inadequate task design or insufficient training, the work efficiency of the space crew may decrease and the likelihood of mission failure increases.

NASA has developed several tools with which to monitor the cognitive performance of astronauts in space, such as the performance assessment workstation (PAWS) (Shehab et al., 1998) and the spaceflight cognitive assessment tool for Windows (WinSCAT) (Kane et al., 2005). Studies were also conducted onboard several space vehicles to analyze the effects of the space environment on human cognitive capabilities (Benke et al., 1993; Manzey et al., 1995; Leone et al., 1995; Eddy et al., 1998; Manzey et al., 1998; Fowler et al., 2000; Kelly et al., 2005; Paloski et al., 2008; Grabherr and Mast, 2010). Studies on astronauts' cognitive capabilities in space obtained inconsistent results. Although most researchers agree that memory and reasoning do not decline in space, whether spatial processing functions and perceptual-motor functions are similarly free of decline remains a matter of debate.

Researchers have shown that cognitive abilities are valid predictors of human performance in various areas, and the cognitive demands in different tasks are seldom identical (Hunter, 1986; Ackerman, 1992; Schmidt, 2002; Bertua et al., 2005; Sommer et al., 2008; Guzel and Sener, 2009; Thomas, 2010; Henderson, 2010; Sulistyawati et al., 2011). Reseaches also show that specific cognitive ability,

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such as spatial abilities, can be improved by training (Martín-Dorta et al., 2008; Hegarty et al., 2009; Geng et al., 2011). So identifying the cognitive demands of the tasks is quite useful for selection and training of the workers.

For manned spaceflight tasks, which are of high risks, identifying the critical cognitive demands is particularly beneficial. However, while various studies have investigated the changing trends of cognitive capabilities of the flight crews in several space missions, few of these studies addressed the cognitive demands of specific spaceflight task, such as the manual RVD task. As pointed out as a knowledge gap by researchers of the NASA Human Health and Performance Program, "There is little experimental evidence demonstrating the effects of disorientation and/or interindividual differences (e.g., in spatial skills) on supervisory control (e.g., space telerobotic operations and vehicle docking)" (Paloski et al., 2008). The current study aims to identify the critical spatial abilities demanded by the manual RVD task. Knowing the critical cognitive demands in manual RVD serves as a useful guide not only for crew training and selection, but also for in-flight cognitive performance monitoring.

2. The manual RVD task and the spatial ability components

2.1. The manual RVD task

Space rendezvous and docking generally involves two spacecrafts, namely, a chaser spacecraft and a target spacecraft. In the manual RVD simulator, the operator, displays, and controllers form a closed loop, as shown in Fig. 1 (Wang and Jiang, 2011; Wang et al., 2011). Video images of the target spacecraft (e.g. a full or partial view of the spacecraft or the cross drone, as shown in Fig. 2) obtained from the cameras are displayed on the monitoring interface. Numerical data obtained from the sensors which indicate the relative position and attitude of the two spacecrafts can be overlaid on the edge of the interface (displaying the numerical data is optional in the simulation system). The operator which is fastened to the bucket seat in the cockpit observes the information displayed on the monitoring interface and manipulates the controllers to complete the manual RVD task (Zhang et al., 2011). The system includes two controllers in the chaser spacecraft: one translation controller, shown in Fig. 3(a), which controls the X, Y, and Z axes of the chaser's position, and one orientation controller, shown in Fig. 3(b), which controls the yaw, pitch, and roll of the chaser's attitude. RVD performance, such as control time and fuel consumption, is automatically recorded by the simulation system.

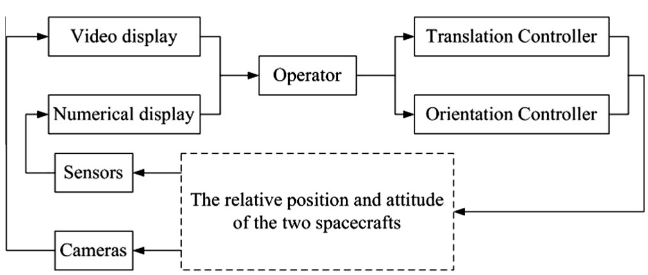

Fig. 1. The display-human-controller loop.

2.2. Components of spatial ability

Researchers agree that there are sub-structures of spatial ability (Linn and Petersen, 1985; Kozhevnikov and Hegarty, 2001; Hegarty and Waller, 2004; McGrew, 2009; Hegarty, 2010), although there is no consensus on the categories and definitions of the sub-components of spatial ability. Recent studies showed a distinction between mental abilities that require spatial transformations of a perceived object and those that involve imagining how a scene looks like from different viewpoints (Kozhevnikov and Hegarty, 2001; Hegarty and Waller, 2004). In this paper, the mental ability that requires spatial transformations of a perceived object has been referred to as object-manipulation ability, and the mental ability that involves imagining how a scene looks like from different viewpoints has been referred to as spatial orientation ability, in accordance with Kozhevnikov and Hegarty (2001) and Hegarty and Waller (2004).

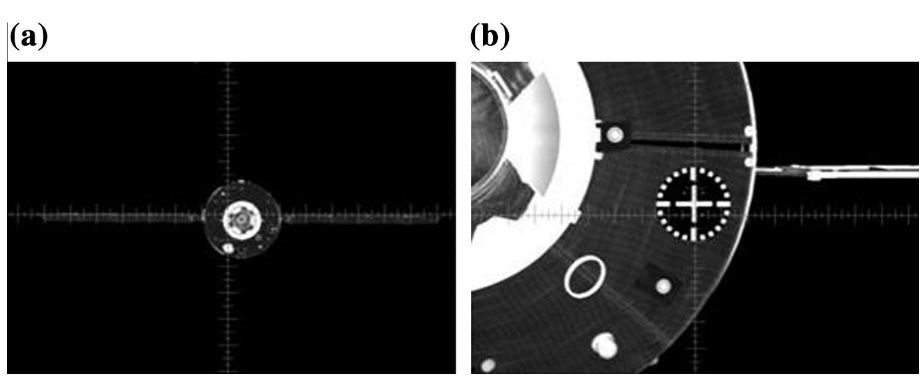

Fig. 2. Video images displayed on the monitoring interface in the manual RVD simulator. (a) When the distance between the two spacecrafts is around 60 meters, the whole profile of the target spacecraft can be seen. (b) When the distance between the two spacecrafts is around 10 meters, the cross drone on the target spacecraft can be viewed clearly, meanwhile only part of the target spacecraft profile can be seen.