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Research report

Quantitative orientation preference and susceptibility to space motion sickness simulated in a virtual reality environment

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ABSTRACT

Orientation preference should appear when variable weightings of spatial orientation cues are used between individuals. It is possible that astronauts' orientation preferences could be a potential predictor for susceptibility to space motion sickness (SMS). The present study was conducted to confirm this relationship on Earth by quantifying orientation preferences and simulating SMS in a virtual reality environment. Two tests were carried out. The first was to quantitatively determine one's orientation preference. Thirty-two participants' vision and body cue preferences were determined by measuring perceptual up (PU) orientations. The ratio of vision and body vector (ROVB) was used as the indicator of one's orientation preference. The second test was to visually induce motion sickness symptoms that represent similar sensory conflicts as SMS using a virtual reality environment. Relationships between ROVB values and motion sickness scores were analyzed, which revealed cubic functions by using optimal fits. According to ROVB level, participants were divided into three groups – body group, vision group, and confusion group – and the factor of gender was further considered as a covariate in the analysis. Consistent differences in motion sickness scores were observed between the three groups. Thus, orientation preference had a significant relationship with susceptibility to simulated SMS symptoms. This knowledge could assist with astronaut selection and might be a useful countermeasure when developing new preflight trainings.

1. Introduction

Space motion sickness (SMS) potentially creates risks regarding crew health, safety, and performance, making it a key issue during a spaceflight's critical first days. SMS severity and duration can vary across individuals (Lackner and DiZio, 2006). This raises the issue of determining which candidate crewmember(s) would be less susceptible to SMS. Researchers have tried to identify personal characteristics linked to SMS susceptibility, such as nystagmus level (Clément and Wood, 2013; Diamond and Markham, 1991; DiZio and Lackner, 1988), otolith asymmetry between the left and right labyrinths (Diamond and Markham, 1992), and velocity storage and dumping characteristics (Cohen et al., 2008; DiZio and Lackner, 1991). Unfortunately, most validation attempts based on a single type of susceptibility test, which involved prediction of SMS incidence or severity as observed under normal mission operations, have not produced prospectively positive correlations (Oman et al., 1986, 1998). This does not mean that these theories are wrong. Because of challenging tasks and limited working hours, activities in orbit differ substantially between crewmembers; thus, comparable conditions for reliable prediction on Earth may simply not be possible. Moreover, it would be difficult to rigorously assess efficacy without large samples. However, a fundamental point is that applicability of predictions should be in accord with provocative conditions and tasks being performed.

The relationship between spatial orientation and SMS has also been studied. Judgments regarding spatial orientation can be made with respect to each of three cues: gravity, vision, and the longitudinal body axis (also called "idiotropic vector;" Mittelstaedt, 1983). These cues are not physically determined but carefully maintained by the nervous system (Barra et al., 2012; Prothero, 1998). Normally, one of the cues is selected by the nervous system as the reference for spatial judgments. When these cues are not aligned, judgments usually depend on the weighted contributions from each cue. Based on this assumption, orientation preference is expected to vary between individuals due to variable weightings

Abbreviations: D, disorientation; N, nausea; IZ, internal *z* axis; O, oculomotor; PU, perceptual upright; ROVB, ratio of vision and body; SD, spatial disorientation; SMS, space motion sickness; SSQ, simulator sickness questionnaire; SV, subjective vertical; TS, total score; VIMS, visually induced motion sickness; VS, visual scene cues; VR, virtual reality.

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of the three cues. Harm and colleagues analyzed several Shuttle astronauts' inflight verbal reports and post-flight debriefing to determine microgravity orientation types based on the selection of rest frames (Harm and Parker, 1993; Harm et al., 1998; Stroud et al., 2005). The authors found that some astronauts apparently increase the weight given to visual scene cues (VS), while others become more dependent on the body's internal *z*-axis (IZ). After comparing susceptibility to SMS, those VS astronauts had greater symptoms than IZ astronauts. Similar findings were reported by Clément and Reschke (2008).

Orientation preference could therefore be a potential SMS predictor. In this study, we tried to confirm this issue on Earth, which has the potential to help develop new countermeasures used in astronaut selection and preflight training. In order to perform this validation, subjects' orientation preferences should be determined, and typical motion sickness that represents SMS conflicts should be induced.

It was argued whether an individual's orientation preference remains unchanged when coming into an unfamiliar environment. This issue has been studied during the STS-90 Neurolab mission by Oman et al. (2003), and results indicate consistent differences between individuals in the relative weighting assigned to visual and body cues regardless of gravitational conditions. Thus, astronauts' orientation preferences can be determined on Earth. Orientation preference on Earth is not so obvious since vision and body cues are neutralized by gravity everywhere; thus, classifications based on verbal reports may be imprecise. Stroud (2004) developed an experiment to study the relationship between orientation preference and SMS induced in a virtual reality environment. In his experiment, participants' orientation preference was initially determined by the median vection latency time, and the Simulator Sickness Questionnaire (SSQ) measured the severity of motion sickness. Results were consistent with a previous study showing that VS participants generally exhibited more symptoms than IZ participants across most SSQ scores (except for nausea). However, one issue should be noted in which vection is usually a prerequisite for motion sickness to occur, and increases in motion sickness symptoms are consistently preceded by vection (Hettinger et al., 1990).

SMS is considered a form of motion sickness, and its physiological characteristics parallel those of motion sickness on Earth, except that pallor is not present (Oman et al., 1986). Motion sickness on Earth can be provoked by motion but also by viewing moving images or designed visual scenes in a virtual reality (VR) environment using any artificial display. However, insusceptibility to Earthly motion sickness does not guarantee that the astronaut will also be free from SMS during his/her flight. This suggests that the underlying cause of SMS differs from that of typical motion sickness, and the key factor to simulate SMS on Earth is not a stimulus' physical intensity but the relation to provocative conflicts. Researchers have investigated and confirmed susceptibility to SMS and sickness induced by centrifugation (SIC, i.e. after a 1 h centrifuge run from $3 \times G$ to $1 \times G$) are correlated (Ockels et al., 1990; Albery and Martin, 1996; Bles et al., 1997; Nooij et al., 2007, 2008, 2011). The results indicated that astronauts who experienced SMS during orbital flight were also found to be more susceptible to SIC. Nooij et al. (2007, 2011) suggested that the effects of transitions from 1 to $0 \times G$ and from 3 to $1 \times G$ both indicate that the body is maladapted to the "Novel" gravitational environment, concluding that SIC and SMS are responsible for the same underlying conflict between sensed and expected vertical. This is based on subjective vertical conflict theory (Nooij et al., 2007; Groen et al., 2011; Bles et al., 1997).

Visually induced motion sickness (VIMS) has also been used to reproduce SMS symptoms. Although gravity cannot be eliminated on Earth, its contribution to spatial orientation in the simulated environment can be negated (Dyde et al., 2009; Ortega and Harm, 2008; Marcus et al., 1993). This can be achieved by keeping the gravity vector constant with respect to the subject, while his or her subjective orientations are changed by perceiving visually induced self-motion. Therefore, the subject achieves "graviceptor stabilization" without stimulating the gravity-dependent vestibular system (Ortega and Harm, 2008; Parker and Parker, 1990). The subject can then compensate for the absence of orientation signals from the otoliths by increasing reliance on vision, semicircular canal inputs, and neck position information. A similar transition occurs upon entry in weightlessness. The VR system has long been used as a way to induce VIMS symptoms (Bos et al., 2008; Hettinger and Riccio, 1992), as it is easily reconfigurable and can be used to represent both highly unnatural as well as realistic environments. NASA developed preflight training for mitigating SMS and spatial disorientation (SD) using a device for orientation and motion environments (DOME; Harm and Parker, 1994; Reschke et al., 1998; Stroud et al., 2005; Taylor et al., 2011; Heer and paloski, 2006). It consists of a 3.66 m spherical dome with an interior VR system designed for virtual performance of operational-type tasks. Changing the visual environment around a fixed individual inside the DOME produces simulation of SMS. It is thought that astronauts can develop sensory-motor programs appropriate for microgravity and can learn to rapidly switch from $1 \times g$ to microgravity. This has provided a 33% improvement in SMS symptoms among participating crewmembers as compared with those who had not participated in the training (Ortega and Harm, 2008).

Based on the aforementioned literature, we speculate that one's orientation preference remains constant as gravitational conditions change, and SMS symptoms can be reproduced in a virtual environment. In the current study, we developed a paradigm to examine the relationship between orientation preference and motion sickness induced by a VR environment on Earth. The specific issue of accurate and quantitative assessment of one's orientation preference was addressed in the present study. Specifically, we improved upon previous work by altering methods for measuring and classifying orientation preference, and the ratio of vision and body vector (ROVB) was chosen as the indicator. VIMS symptoms representing similar sensory conflicts as SMS were induced using a VR environment. Methods and results are summarized in the following sections with a detailed discussion afterwards.

2. Materials and methods

2.1. Overview

The main devices used in the present study were three high-definition TV screens (LG 55LM6600-CE), simply referred to as screens (Fig. 2). Each screen was 55 in with a 1920×1080 resolution. A light-tight room (*L*: 4 m, *W*: 4 m, *H*: 2 m) was built for the screens to enhance immersion within the virtual scene. A PC computer (equipped with an NVidia Quadro K5000 video card) was used to generate the virtual scene rendered by OGRE (Object-Oriented Graphics Rendering Engine).

Thirty-two naive participants (9 females and 23 males) aged 20 to 39 years (mean age 29.5, SD = 5.4) participated. All were healthy volunteers with normal functioning vestibular and visual systems who were not currently taking any medications. Participants gave informed consent prior to participating, and the ethics committee from the China Astronaut Research and Training Center duly approved the experimental protocols.

2.2. Determining orientation preference

The perceptual upright (PU) was used to measure participants' orientation preference. The PU represents the orientation at which