VISUALLY INDUCED MOTION SICKNESS: EFFECTS OF TRANSLATIONAL VISUAL MOTION ALONG DIFFERENT AXES

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A laboratory experiment compared the effects of navigating through a virtual environment in inducing symptoms of motion sickness, specifically nausea. The effects of simulated fore-and-aft, lateral and vertical oscillations were compared. Navigation in all three translational directions significantly increased self-reported levels of nausea and Simulator Sickness Questionnaire scores.

Introduction

About 30% of the population are susceptible to motion sickness (Griffin, 1990; So et al., 1999). Navigating through a virtual environment (VE) while remaining physically stationary can cause visually induced motion sickness (VIMS). Typical symptoms include nausea and eye fatigue. VIMS has been the subject of many studies for over the last forty years (e.g., Bonato et al., 2005; Bos and Bles, 2004; Ji et al., 2009; Kennedy et al., 1968, 1990; Kiryu et al., 2007; Money and Wood, 1968; Lo and So, 2001; Oman, 1982; Reason, 1978; So and Lo, 1999; So et al., 2001, 2002; Webb and Griffin, 2003; Wilson, 1996; Young and Oman, 1968; and Zwerling, 1947). In 2005, the International Organization for Standardization (ISO) published its International Workshop Agreement 3 on Image Safety which included a large section on the harmfulness and prevention of VIMS (IWA3, 2005). Since then, both the ISO and Commission Internationale de l'Eclairage (CIE) have commissioned working groups to draft standards concerning VIMS (So and Uijke, 2010). In 1999, the concept of a cybersickness dose value (CSDV) was reported (So, 1999) and studies have shown that CSDV can explain over 67% variations in rated levels of nausea.

Lo and So (2001) compared levels of VIMS generated from watching a visual scene with oscillations around different rotational axes in a VE. In that study, scene movements were presented with sine wave oscillations around the pitch,

yaw and roll axes at 30 degrees per second (r.m.s.). Results indicated that watching rolling visual scene caused the highest number of viewers to report at least moderate nausea. There has been no similar study investigating the effects of scene movements along different translational axes in VEs on the level of VIMS. Sensory mismatch between visual and vestibular signals in real world translation situations are common. Examples of people experiencing such mismatches range from players of virtual reality (VR) games to occupants of tall buildings (Griffin, 1990; So *et al.*, 2001).

Objectives and hypotheses

The purpose of this study was to investigate the effects of translational navigation in a VE along three different axes (i.e., fore-and-aft, lateral, vertical) on the level of VIMS. We aimed to search for a dominant influencing axis for VIMS among the three translational axes. Watching the same VE without navigation was added as a control condition.

Method and Design

The experiments investigated four levels of translational navigation: no navigation (control condition), fore-and-aft translational navigation, lateral translational navigation, and vertical translational navigation. This gave four conditions. A full factorial between-subject design with 32 (16 male and 16 female) participants was used. Each participant was exposed to a 15-minute virtual reality simulation according their assigned condition. These subjects were university students 18 to 22 years old. Each of them was paid HK$60 as compensation for his/her time for each experimental session. All participants were consenting volunteers who were healthy and not taking medication. The Human Subject and Research Ethics Committee at the Hong Kong University of Science and Technology approved the experiment.

The virtual scene was constructed using the World-Tool-KitTM running on a Silicon Graphics Onyx II (Silicon Graphics, Inc.) workstation (Figure 1). The program was written in C++ language. The VE was presented on a VR4 (Virtual Research Systems, Inc., USA) LCD Head-Mounted Display (HMD) with a field-of-view of 48 degrees (horizontal) by 36 degrees (vertical). Stereoscopic images were presented according to each individual's inter-pupillary distance. A Polhemus 3-Space magnetic tracker (Polhemus, Inc., USA) was used to measure the head positions and orientations to update the view of the virtual environment (VE). The VE represented a room of 40 metres by 40 metres by 40 metres (like a gymnasium). Four VR simulation conditions were used. In the control condition, participants experienced no navigation. For the other three simulation conditions, participants navigated inside the room along the three translational axes

following a 0.12 Hz sinusoidal pattern of 18 meters amplitude. Before each exposure, participants were asked to complete a Motion Sickness Susceptibility Survey to indicate their general sensitivity to motion sickness. Participants were classified into highly susceptible, not susceptible, and others. Participants within each group were randomly assigned to the four conditions. This was done to minimize susceptibility bias because only about 30% of the population are susceptible to motion sickness (So et al., 1999). All participants were taught to distinguish vection (illusion of self-motion induced by surrounding visual motion) from perceived speed of the surround scene. Kennedy has reported that participants could reliably separate vection from perceived speed (Kennedy et al., 1996).
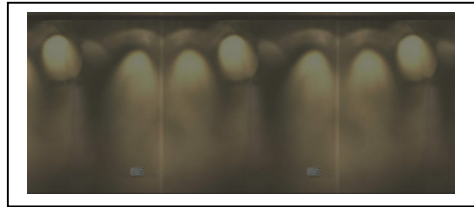

Figure 1 A snapshot of a participant's view of the inner wall of the room.

Before being exposed to the 15 minute VR simulation, each participant completed a pre-exposure Simulation Sickness Questionnaire (SSQ, Kennedy et al., 1993). If a participant reported more than two slight symptoms or had a pre-exposure SSQ total score of more than 10, they were asked to take a rest for 5-10 minutes with their eyes closed. After that, the participants were asked to fill in another pre-SSQ. If the pre-exposure SSQ total score was less than 10, then the experiment proceeded. However, if the pre-exposure SSQ total score was still more than 10, then the participants were asked to come back at another date.

During the 15 minute VR simulation, participants were asked to sit in an up-right posture and turned their heads to the left or right once every 75 seconds in alternate directions. This was done to encourage the participants to be more involved in the VE. These turning movements were coupled with appropriate changes in view-point and caused little conflict between the stimuli given to the vestibular and visual systems. At five-minute intervals, participants were asked to rate verbally their symptoms of nausea on a seven-point scale (Golding and Kerguelen, 1992) and their sensation of vection on a 4-point scale (Webb and Griffin, 2002). After the VR exposure, participants were asked to complete a post-exposure SSQ. During the simulation, if a participant reported a nausea rating of 6 (moderate nausea, wanting to stop), the VR simulation was terminated and the participant was asked to complete the post-exposure SSQ. A score of 6 was assigned for the remaining verbal rating reports. Two female participants reported a nausea rating of 6 after 10 minutes of VR exposure.

Results

Data on nausea ratings, vection ratings and SSQ measurements did not adhere to a normal distribution, so non-parametric statistical methods were used to analyze the data. Median nausea and vection ratings are shown in Figures 2 and 3.
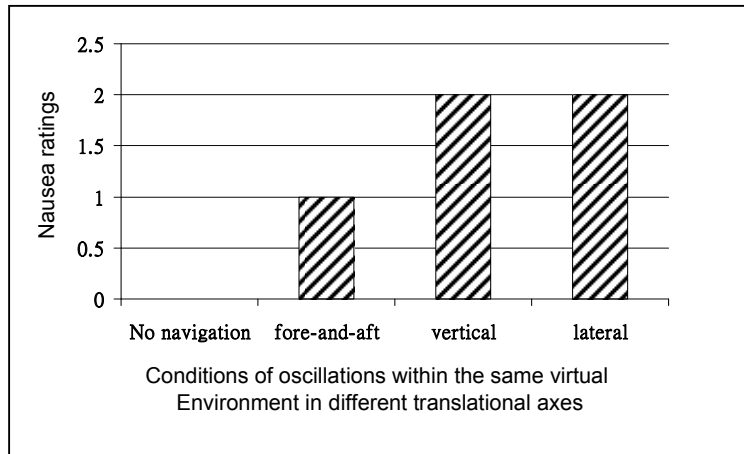

Figure 2 Median nausea ratings (of 8 participants) after 15 minute exposure to VR simulation with stationary scene (control condition) and sinusoidal oscillations in fore-and-aft, lateral, and vertical axes.

Inspection of Figures 2 and 3 indicates that exposure to fore-and-aft, vertical, and lateral visual scene oscillations all caused observable increases in both vection and nausea ratings. Mann-Whitney U tests were conducted to compare the nausea and vection ratings collected at the end of the 15 minute exposures between each of the scene oscillation conditions and the control (no navigation) condition. The results confirm that these increases were statistically significant (nausea: $p \leq 0.001$; vection: $p \leq 0.001$). Similar tests for nausea and vection reported after 5 minute exposure resulted in no significant difference. It was interesting that in the control condition, although none of the eight participants reported any vection, three participants reported a rating of '1' (any unpleasant symptom however slight). Interviews with these three participants after the exposure indicate that the tightness of the HMD and loss of focus (or blurring of images) were the main cause of the slight unpleasant symptoms. Studies have shown that mismatch between demands in accommodation and convergence on stereo images presented on a HMD can cause discomfort (e.g., Hoffman, 2008; Wong et al., 2011). However, this should not be a serious concern in this study because stereo convergence demands were minimal. They were all beyond 2 metres. Participants exposed to vertical and lateral oscillations reported higher average nausea ratings than those exposed to fore-and-aft oscillations (Figure 2). However, the results of Mann-Whitney U tests indicated that the differences were not significant. Similar analyses of the vection ratings also indicated no

significant differences among the three translational axes. Significant correlations were found between individually rated levels of vection and rated levels of nausea ($p \leq 0.001$). Since both vection and nausea increased significantly with exposure duration ($p \leq 0.001$, Friedman signed ranked tests), the correlations between vection and nausea ratings were examined at each of the timing interval (0, 5, 10 and 15 minutes). Significant correlations were found only at 10 and 15 minutes.
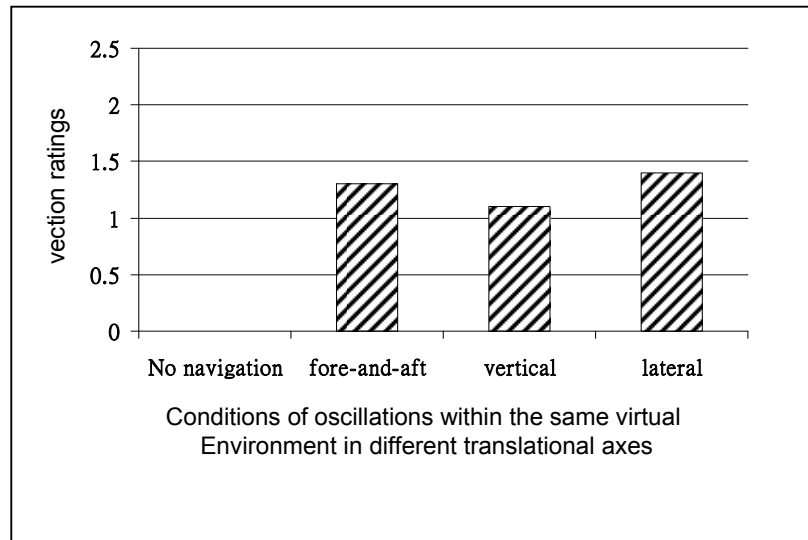

Figure 3 Median vection ratings (of 8 participants) after 15 minute exposure to VR simulation with stationary scene (control condition) and sinusoidal oscillations in fore-and-aft, lateral, and vertical axes.

Analyses of the SSQ scores indicated that post-exposure SSQ total scores collected in all three oscillation conditions were significantly higher than those collected in the control condition. Nausea and disorientation sub-scores were slightly higher with lateral visual oscillations, but the differences were not significant. The lack of significance might have been due to the relatively short exposure duration. Future studies with longer durations are desirable.

Effects of gender were also investigated. Female participants reported significantly higher average nausea ratings ($p \leq 0.05$). Some interaction between gender and the effects of the axes was observed. Future studies with more participants are needed to confirm any gender effect.

Discussion and Conclusions

The results of the experiment indicate that exposure to fore-and-aft, lateral and vertical visual oscillations can all cause significant increases in self-reported levels of nausea, vection, and in SSQ scores ($p \leq 0.05$). Exposure to 15 minutes of VR scene oscillation resulted in similar levels of visually induced motion sickness (VIMS) among the viewers regardless of the orientation of the oscillation. This finding is of importance because the spatial content of the views along the three translational axes inside the virtual environment were similar, and the lack of significant difference could suggest that a single dominate axis of scene movement does not exist. Future work with longer exposure durations are needed.

This study used a between-subject design where each participant was exposed to only one condition. This avoided transfer of training and adaptation, but inter-subject variability in sickness susceptibility could have masked significant main effects. Future studies should consider using a within-subject design to reduce the influence of idiosyncratic variability on the main effects.

Results of this study suggests that exposure to translational scene oscillation in a VE should be limited to 5 minutes if VIMS is to be avoided. The search for a dominating axis around which visual scene movement can cause significantly higher levels of VIMS is important. The identification of any dominant axis could advance our understanding of the generation of VIMS and help to model and predict levels of VIMS. It could also help to construct a standard test stimulus for VIMS.

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