Cybersickness: An Experimental Study to Isolate The Effects of Rotational Scene Oscillations

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Abstract

Head-coupled virtual reality systems can cause symptoms of sickness (cybersickness). A study has been conducted to investigate the effects of scene oscillations on the level and types of cybersickness. Sixteen male subjects participated in the experiments. They were exposed to four 20-minute virtual simulation sessions, in a balanced order with 10 days separation. The 4 simulation sessions exposed the subjects to similar visual scene oscillation in different axes: pitch axis, yaw axis, roll axis and no oscillation (speed: 30°/s, range: +/-60°). Verbal ratings of nausea level were taken at 5 minute intervals and sickness symptoms were measured before and after the exposure using the Simulator Sickness Questionnaire (SSQ). Significant differences were found between the no oscillation condition and the oscillating conditions. With scene oscillation, nausea ratings increased significantly after 5-minute exposure for all the oscillation axes (pitch, yaw, and roll axes). Total sickness scores were obtained from the SSQ and their profiles with different scene oscillation axes were presented.

Introduction

A virtual reality system allows a user to interact with a computer-generated (virtual) environment. Images forming the virtual environment are presented through either a head-mounted display (HMD) or a multiple screens projection system (e.g., CAVE^{TM}). Users can select their views by moving their heads (i.e., a head-coupled virtual reality system, [4]) and can navigate through the virtual environment with a mouse or joystick-type device. Virtual reality systems have been used in a wide range of applications such as simulation training (e.g., driving simulation: [7]; flight simulation: [2]; teleoperation: [11]; and data visualization: [1].

Although virtual reality systems are powerful in generating an apparent sense of presence, they have some shortcomings. One of them is the associated side effect of sickness. Users of virtual reality systems can suffer from symptoms similar to those of motion sickness. The term ‘cybersickness’ has been used to describe the phenomenon of motion sickness with virtual reality systems [9]. Regan (1995) studied the effects of a head-coupled virtual reality system [10]. In her study, 61 percent of the total 150 subjects reported symptoms of malaise. She stated that after the use of a virtual reality system for 20 minutes, the most common symptoms were dizziness, headaches, eyestrain, stomach discomfort and severe nausea. Five percent of the subjects withdrew from the experiment due to severe nausea or severe dizziness. So (1994) studied the effect of lags on motion sickness with a head-coupled virtual reality system [12]. He reported that about 60 percent (29 out of 48) of the subjects suffered ‘general discomfort’ after a 20-minute flight simulation. Four subjects had to withdraw from the study after reporting moderate nausea. In the above studies, the axes of scene movement were not controlled. A review of the literature reveals that there have been no published studies on the effects of scene movement axes on cybersickness.

In studies with seasickness, Lawther and Griffin (1986) reported that the vertical axis ship motion was the main cause of motion sickness [8]. This conclusion subsequently led to the development of the Motion Sickness Dose Value (MSDV) for predicting seasickness based on the measured vertical motion of a ship. Similarly, if a dose value relationship between the rated level of cybersickness and the amount of scene movement in a virtual environment is to be developed, the effects of the scene movement axes should be studied.

Method

Objectives and hypotheses

The objective of this study is to determine the relationship between axes of visual scene oscillation and the rated level of cybersickness. It was hypothesized that (i) visual scene oscillations in the pitch and roll axes would produce higher levels of sickness than scene oscillations in the yaw axes; and (ii) a virtual environment without scene oscillations would produce lower levels of sickness. The former hypothesis was based on the assumption that the effects of apparent self-motion in the pitch and roll axes would be larger due to the absence of the appropriate gravitational stimuli.

Subjects

Sixteen male volunteers participated in the experiment. They were university students and staff members with an average age of 26 years old. A payment of HK$200 was given to each subjects at the end of the experiment as a compensation for their time and travel expenses. Subjects of the same gender were used in this study because it has been reported that gender has a significant effect on motion sickness susceptibility [3].

Apparatus

The virtual scene was constructed using a virtual reality authoring software (dVISE) running on a Silicon Graphics Onyx workstation. Images were presented on a VR4 LCD head-mounted display with a field-of-view of 48° horizontal and 36° vertical. Head orientation was monitored with a Polhemus FastTrack system. The experimental room was air-conditioned with an average temperature of about 23°C. The inherent response lag of the experimental virtual reality system to head movement was about 67ms. This comprises 33.3ms computational lag; 16.7ms video frame delay; and 16.7ms head tracker delay.

Procedure

This experiment investigated three independent variables: (i) duration of exposure (0 to 20 minutes); (ii) axes of scene oscillations (pitch, yaw, and roll axis); and (iii) with and without scene oscillations. It was a within-subject full factorial experiment with four conditions: scene oscillations in pitch, yaw, and roll axes, and no scene oscillation. The order of presenting the conditions was balanced using four 4x4 Latin square designs and exposure to each condition was separated by at least 7 days (10 days, on average). The speed of scene oscillation was 30° per second and the range of oscillation was +/-60° (i.e. 120°). This speed of oscillation was comparable to speeds used in studies of vection-induced motion sickness caused by rotating drums (e.g., [13]). The range of scene oscillation was an arbitrary choice of what is expected in a typical virtual simulation application. A sample scene is shown in Figure 1. Before each exposure, the subjects were required to rest for 5 minutes in the air-conditioned experimental room. They were then asked to complete a pre-exposure Simulator Sickness Questionnaire (SSQ) documenting the severity levels of 27 sickness symptoms [6]. One-minute practice was given for the subjects to familiarize them with the equipment followed by a 20-minute virtual simulation. Nausea ratings were obtained verbally at five minute intervals according to a seven-point scale: 0 - no symptom; 1 - any unpleasant symptom, however slight; 2 - mild unpleasant symptom; 3 - mild nausea; 4 - mild to moderate nausea; 5 - moderate nausea but can continue; 6 - moderate nausea, want to stop. After the exposure, subjects were asked to complete a post-exposure SSQ and a questionnaire assessing the realism of the simulation and the sense of self-motion during the simulation. The subjects were then asked to rest for about 10 minutes before they were discharged.

During the 20-minute virtual reality simulation, subjects were asked to sit in an up-right posture with their backs touching the back-rest. Also, they were instructed to keep their heads straight in a forward looking posture. This eliminates the influence of head movement which may be a subject of interest for future studies.

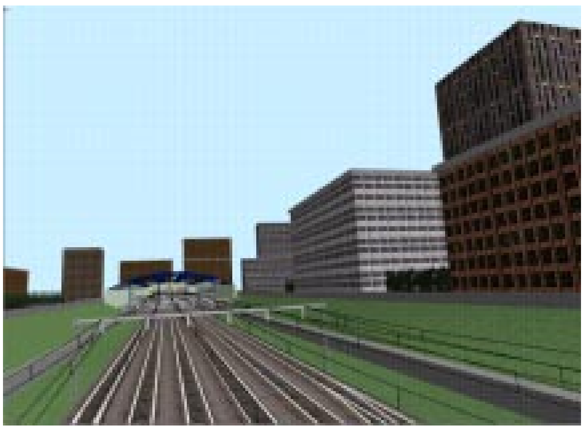

Figure 1. A sample scene of what the subjects saw on the head-mounted display. The scene contains some buildings, a train station, tracks, cables, and bridges.

Results and discussion

Normal plots indicated that both the nausea ratings and SSQ scores have near normal distribution. The subjective nausea ratings are shown in Figure 2. Inspection of the figure indicates that, with scene oscillations, ratings increased with increasing time of exposure. Results of an ANOVA (General Linear Model) indicate that duration has a significant main effect on nausea ratings ($F_{4,255} = 50.3$, $p<0.005$). Post-hoc analysis using Student-Newman-Keuls tests showed that the effects of exposure duration were significant after 5 minutes for all axes (pitch: $p<0.05$; yaw: $p<0.05$; roll: $p<0.05$). Although the nausea rating increased with exposure duration, the rate of increasing slowed down after 15 minutes for oscillations in the pitch and roll axes. For the yaw axis oscillation, there was no sign of slowing down. Studies with longer duration to further understand this phenomenon is desirable. Inspection of Figure 2 shows that, after 20 minutes of exposure, mean nausea ratings with oscillations in the three axes are similar. Results of an ANOVA show that the axis of scene oscillation did not have a significant effect on the nausea ratings ($F_{2,255} = 0.75$, $p>0.47$).

Without scene oscillation, the mean rated level remained as near zero (i.e. ‘no symptom’) and the effects of duration was not significant for exposure time up to 15 minutes ($p>0.1$, Student-Newman-Keuls). After 20 minutes of exposure, however, the average nausea ratings did increased when compared to that measured at 0 minute. A possible reason is that subjects suffered from some unpleasant symptoms caused by the head-mounted display (weighted 0.94kg). This explanation is confirmed by the observation that the highest nausea rating obtained in the condition without scene oscillation was ‘1’, which corresponds to ‘any unpleasant symptom, however slight’. There were significant differences between the no scene oscillation condition and the conditions with scene oscillations ($F_{1,318} = 62$, $p<0.001$). This suggests that scene movement is essential in causing cybersickness.

Among a list of 27 symptoms, over 50 percent of the subjects exposed to scene oscillations reported an increase in general discomfort, eyestrain, fullness of head, fatigue (pitch axis scene oscillation only), and difficulty in focusing (roll axis scene oscillation only). Total sickness scores and the three associated sub-scores: oculmotor (O), nausea (N), and disorientation (D) were obtained from the SSQ data (Figure 3). An ANOVA was conducted to test the difference in the sickness scores with and without scene oscillation. The results indicate that the presence of scene oscillation has a significant effect on all the sub-scores and the total sickness score (nausea sub-score: $F_{1,62} = 5.9$, $p<0.02$; oculomotor sub-score: $F_{1,62} = 7.5$, $p<0.01$; disorientation sub-score: $F_{1,62} = 7.4$, $p<0.01$; total sickness score: $F_{1,62} = 8.5$, $p<0.005$).

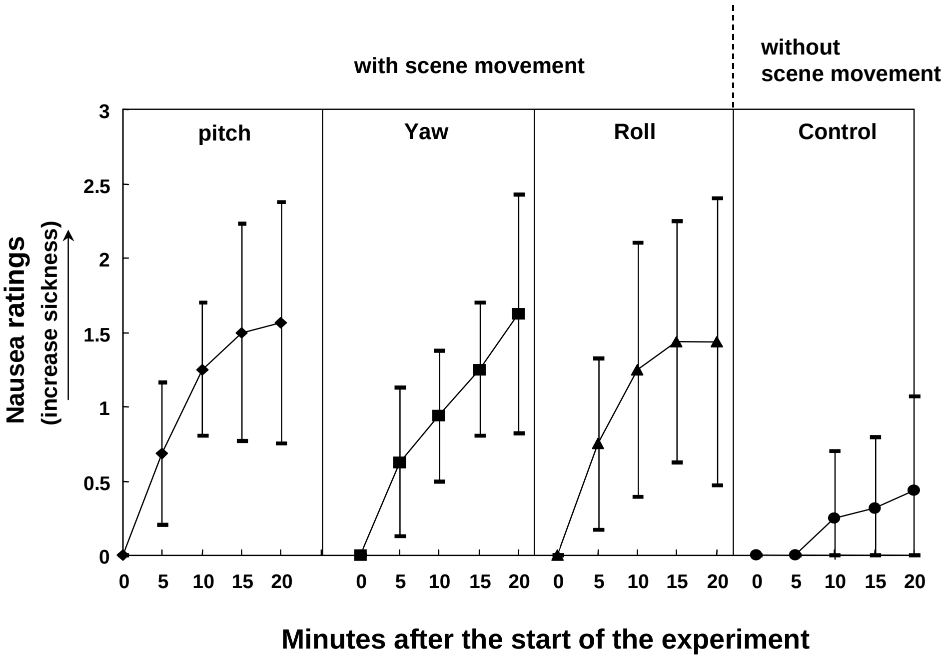

Figure 2. Mean nausea ratings as functions of exposure duration (data from 16 subjects, +/- standard deviations are shown where appropriate).

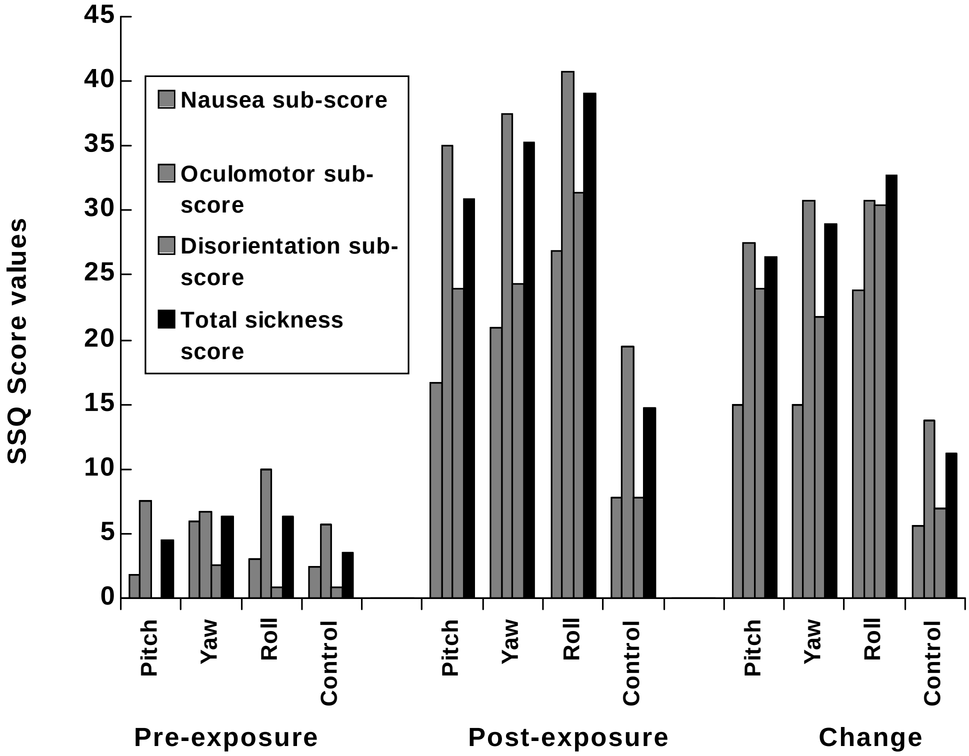

Figure 3. Sickness scores before and after the virtual simulation exposure as functions of scene oscillation axes.

With the scene movement, the post-exposure total sickness score data ranged from 30 to 38, which are comparable to the published data (19 - 55) from [5]. In this study, the sub-score pattern was consistently as O>D>N, which was different from the D>N>O pattern reported previously [5]. Further investigation is needed to determine the reason for the difference.

Conclusion and future work

The presence of scene oscillation in a virtual environment can significantly increase the rated level of nausea and simulator sickness scores. All other things equal, scene oscillation in different rotating axes are likely to have similar effect on the level of cybersickness.

With scene oscillations, exposure to a virtual environment for a period longer than five minutes causes a significant increase in the nausea rating. In the absence of scene oscillation, viewing a stationary virtual environment for up to 15 minutes is not likely to cause a significant increase in the nausea level. In this study, all subjects were asked to keep their heads still. Further experiments investigating the interactions between scene oscillations and head movements are desirable.

Acknowledgement

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