QUANTIFYING SCENE MOVEMENT WITH 'SPATIAL VELOCITY' AND ITS EFFECTS ON CYBERSICKNESS

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Viewing wide field-of-view scene movement with a Virtual Reality (VR) display can cause symptoms of cybersickness (e.g., nausea and headache). It has been known that cybersickness is a type of vection-induced motion sickness. Since vection is associated with the perception of moving scene, two studies have been conducted to investigate the effects of different scene movements on levels of cybersickness. The velocity and complexity of the scene movements were quantified by a previously reported metric called 'spatial velocity (SV)' while the levels of cybersickness were measured in terms of nausea ratings and Simulator Sickness Questionnaire (SSQ) scores. Results showed that in both experiments, both the nausea ratings and the SSQ total sickness scores increased significantly with increasing SV in the dominant axes of scene movement. Potential uses of the SV metric for formulating a CyberSickness Dose Value (CSDV) are discussed.

INTRODUCTION

A Virtual Reality (VR) system enables a user to interact with a computer-generated 'virtual' environment (Furness and Barfield, 1995). VR systems are extensively used in applications where dynamically moving scenes are presented. For example, driving simulation (Bayarri *et al.*, 1996), flight simulation (Haas, 1984), and entertainment (DeFabti, T.A., 1994). However, symptoms of motion sickness (e.g., nausea and headache) have been reported in many studies in which participants navigated through a virtual simulation (e.g., Stanney and Kennedy, 1997, 1998; Kolasinski *et al.*, 1998; Draper, 1998; Wilson *et al.*, 1997; Finch and Howarth, 1996; Regan, 1995; and So, 1994). This type of sickness has been referred to as 'cybersickness' (McCarley and Sharkey, 1992) and its occurrence has been explained by the theory of sensory conflict (Oman, 1993; Griffin, 1990; Reason and Brand, 1975). When an observer views a wide field-of-view moving scene, there is commonly an illusion of self-motion (vection) in the opposite direction. In the absence of the appropriate physical motion, the experience of vection can be nauseogenic. This phenomenon has been also referred to as "vection-induced motion sickness" (e.g., Hettinger and Riccio, 1992).

Although there have been many studies concerning cybersickness, the effect of scene movement has not been well quantified. The main reason is that it is very difficult to quantify scene movement as an independent variable. Kennedy *et al.* (1996) reported the first attempt to quantify the visual stimuli for the study of cybersickness. Although the quantified value, referred to as the 'human judged kinematic cluster scores', has been shown to correlate with levels of cybersickness, the procedures in calculating the cluster scores for scene movements have been labor intensive: greater than 500 hours of descriptive tape analysis by human observers in addition to computational analyses. In 1999, the authors reported an alternative method to quantify the visual scene movement using a metric called 'spatial velocity (SV)' (Lo and So, 1999, Lo, 1998). This SV metric is a 3x2 matrix (Equation 1) and has two main components: (i) average spatial frequencies (*SF*) measuring the average spatial complexity of the virtual scene in horizontal (SF_{horiz}), vertical (SF_{vert}), and radial (SF_{rad}) axes; and (ii) scene movement velocities (*V*) relative to the viewers in fore-and-aft (V_x), lateral (V_y), vertical (V_z), pitch (V_{pitch}), yaw (V_{yaw}), and roll (V_{roll}) axes. The formulae of the SV metric is as follows (adapted from Lo and So, 1999):

$$\begin{bmatrix} SV_x & SV_{roll} \\ SV_y & SV_{yaw} \\ SV_z & SV_{pitch} \end{bmatrix} = \begin{bmatrix} SF_{rad} & SF_{horiz} & SF_{vert} \end{bmatrix} x \begin{bmatrix} V_x & V_{roll} \\ V_y & V_{yaw} \\ V_z & V_{pitch} \end{bmatrix}$$

Equation 1

Where $SV_{x,\ y,\ z,\ yaw,\ roll,\ pitch}$ are the spatial velocities of the six axes; $SF_{horiz,\ rad,\ vert}$, are the spatial frequencies of the horizontal, radial, and vertical axes (unit: cycles / degrees); $V_{x,\ y,\ z,\ yaw,\ roll,\ pitch}$ are the scene movement velocities in the six axes (unit for $V_{x,y,z}$ is: metres / seconds; for $V_{yaw,roll,pitch}$ is: degrees / seconds).

The SV metric is in six axes and the unit for the translational axes are 'cycles x metres / seconds x degrees' and the unit for the rotational axes are 'cycles / seconds'. The 'cycles' refer to the contrasted cycles of the picture elements across a scene. The 'degrees' and 'metres' refer to the angular and translational measurements of a view of the virtual scene, and the '1 / seconds' reflect the velocity measurements of scene movements. The measurement of scene movement velocities can be completely automatic through a sub-routine insert in a virtual reality simulation program. For the spatial frequency measurement, most of the calculation is performed automatically through a MATLAB™ batch file. The only portion that requires human involvement is the random sampling and capturing of about 5 to 10 still pictures of the virtual environment. Details of how to calculate 'Spatial Velocity (SV)' can be found in Lo and So (1999). The present paper presents two studies conducted to investigate the effects of scene movement, as measured by SV, on rated levels of cybersickness.

METHOD

Two experiments were conducted to study the effects of 'Spatial Velocity (SV)' on levels of cybersickness. Both experiments had SV as the independent variable. Experiment one had three levels of SVs (0.03; 0.44; and 2.00 cycles x metres / second x degrees in the fore-and-aft axis, 0.03; 0.37; and 1.71 cycles / seconds in the yaw axis). These three levels of SVs were generated by manipulating the levels of scene complexity. Experiment two also had three levels of SVs (0.72; 0.91; and 2.00 cycles x metres / second x degrees in the fore-and-aft axis, 0.59; 0.77; and 1.71 cycles / seconds in the yaw axis). These three levels of SVs were generated by manipulating the scene velocity. Both experiments used the same apparatus: VR4 Head-Mounted Display, head tracker, and a Silicon Graphics Oxyn2 workstation. A similar virtual environment was used in both experiments except the number of virtual objects, the texture mappings, and the speed of navigation would be different as the scene complexity and velocity varied. The scene contains a city, railway lines, power cables, trees, and a train station. Subjects in both experiments were exposed to an auto-piloted navigation path along a virtual railway line. Most of the path movements were in the fore-and-aft and yaw axes. An example of a scene viewed by the participants is shown in Figure 1.

Figure 1. A snap shot of a virtual environment used in the experiment (with the highest scene complexity). The virtual environment was created using dVISE.

The two experiments had seventy-two participants, they were healthy male university staff and students aged between 19 and 39. All of them were frequent users of computers.

Subjects with the same gender were used because it had been reported that gender has a significant effect on motion sickness susceptibility (Griffin, 1990). A survey of 250 male and 250 female Hong Kong Chinese has indicated that female has a significantly higher self-rated susceptibility to motion sickness (So *et al*., 1999). The duration of the Virtual Reality simulation was 30 minutes and at 30 seconds intervals, participants were asked to turn their heads momentarily to one side (about 60°) and verbally describe what they see to the experimenter. This was done to ensure that the participants were paying attention to the Virtual Reality simulation throughout the experiment. The directions of turning their heads were altered between left and right consecutively. At the beginning of the experiment, one-minute practice with the Virtual Reality apparatus was given to all the subjects. After that, they were asked to rest for five minutes to minimize any unwanted influence from previous activities. A pre-exposure Simulator Sickness Questionnaire (SSQ) was then completed before they put on the Head-Mounted Display (HMD) again for a 30-minutes Virtual Reality simulation. The SSQ was adapted from Kennedy *et al*. (1993). Subjects remained seated throughout the simulation. At five-minute intervals from the start of the simulation, subjects were verbally asked to rate their levels of nausea using a seven-point nausea 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. This scale was used in previous studies concerning cybersickness (So, 1994; So and Lo, 1999) and motion sickness (Woodman and Griffin, 1997). The subjects were also asked to verbally rate their sense of 'self-motion illusion' on a four-point scale: '0' - none; '1' - slight; '2'- moderate; '3' - strong. After the simulation session, the subjects were asked to complete a post-exposure SSQ. The subjects were required to stay in the laboratory until all the sickness symptoms had been dissipated. The experiment confirmed to the ethical standard of the Human Subject Committee of Hong Kong University of Science and Technology.

RESULTS

In both experiments, both the nausea ratings and the rated sense of 'self-motion illusion' increased with increasing time of exposure. ANOVAs were conducted and the duration effects were significant for both experiments (nausea rating: $p<0.001$; self-motion illusion: $p<0.001$). Strong correlation relationships between the levels of nausea ratings and the levels of 'self-motion illusion' were found ($\alpha = 0.8$, $p<0.001$ for both experiments). The pre and the post-exposure SSQ questionnaires were analyzed and the Total Sickness Severity scores are plotted against the levels of 'Spatial Velocity (SV)' in the fore-and-aft axis (Figure 2).

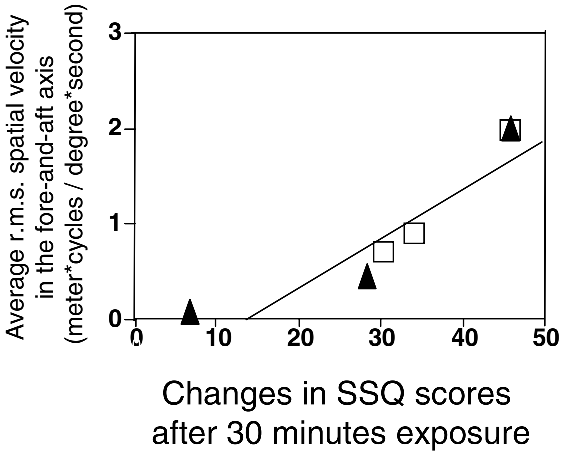

Figure 2. Levels of SSQ Total Sickness Severity scores with Different levels of Spatial Velocity (SV). (▲: data the experiment manipulating scene complexity; ?: data from experiment manipulating scene velocity).

Inspection of the figure shows that as the SV increases, the level of the Total Sickness Severity scores also increases. Results of ANOVAs indicated that, in the domain axes of scene movement (i.e., the fore-and-aft axis and the yaw axis), SV had significant main effects on the levels of Total Sickness Severity score and the nausea ratings ($p<0.001$, for both experiments). This indicated that both increases of scene complexity and scene velocity caused significant increases in SSQ scores and nausea ratings.

DISCUSSION

The duration effects with nausea ratings were consistent with the findings of previous studies (e.g., Regan, 1995). The finding that levels of nausea ratings increases with increasing exposure duration agrees with the sensory conflict theory. The strong correlation relationships found between the levels of 'self-motion illusion' and nausea ratings in both experiments are consistent with the previous prediction that cybersickness is a type of vection-induced motion sickness (e.g., Hettinger and Riccio, 1992).

The signification influence of 'Spatial Velocity (SV)' on the levels of nausea ratings and the Total Sickness Severity scores indicates that SV can be a predictor variable for the levels of cybersickness. Theoretically, the metric 'SV' quantifies the levels of scene movement, which should be the main cause of vection-induced motion sickness as predicted by the sensory conflict theory. Experimentally, the levels of SV have been shown to significantly influence the rated levels of cybersickness. This finding is important because if SV is proved to be a reliable measurement of scene movement, a CyberSickness Dose Value (CSDV) can then be developed by integrating the metric SV with exposure duration (So, 1999). Other influences such as field-of-view (FOV), and subject-related factors can be added as addition weightings (e.g., FOV: Dizio and Lackner, 1997; Subject-related factors: Kolasinski and Gilson, 1998). A successful example is the Motion Sickness Dose Value (MSDV) developed for the prediction of the occurrence and severity of seasickness (BSI, 1987; Griffin, 1990). At present, the finding concerning the effects and the use of Spatial Velocity (SV) is still at a preliminary stage, further studies to confirm the results are desirable. The method of calculating SV will also need to be refined (Lo and So, 1999).

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