EFFECTS OF EYE FIXATION ON VISUALLY INDUCED MOTION SICKNESS: ARE THEY CAUSED BY CHANGES IN RETINAL SLIP VELOCITY?

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Watching slowly moving wide field-of-view patterns can cause symptoms of visually induced motion sickness (VIMS) in viewers. A within-subject full factorial experiment was designed to test two hypotheses: 1) when watching patterns rotating at 60 degrees per second (dps), eye fixation increases the peripheral retinal slip velocity leading to a reduction in the levels of VIMS; and 2) when watching patterns rotating at 7 dps, eye fixation increases the peripheral retinal slip velocity leading to an increase in the levels of VIMS. The experimental design used two levels of eye fixation (with and without). Nine participants (4 male and 5 female) were exposed to all four conditions with a week's break between each condition. Results indicated that when watching patterns rotating at 60 dps, eye fixation significantly increased the peripheral retinal slip velocity from 35 dps to 60 dps and reduced the levels of mean nausea from 3.6 to 2.7 ($p < 0.01$). When watching patterns rotating at 7 dps, eye fixation significantly increased the peripheral retinal slip from 2.6 to 7 dps and only slightly increased the levels of mean nausea. The implications of these results are discussed.

INTRODUCTION

Background

Visually induced motion sickness (VIMS) has been the subject of many studies (Boss and Bles, 1998; Howard and Finch, 1999; Ji *et al.*, 2005; 2009; Kiryu and So, 2007; Kennedys *et al.*, 1993; So and Lo, 1999; So *et al.*, 2001; 2002; Stanney *et al.,* 2003; Ujike *et al.*, 2008; Webb and Griffin, 2002, 2003; Wilson, 1996). With the lowering of the cost of virtual reality (VR) displays, the concern for VIMS is shifting from developers of military simulators to developers of VR games (Ujike *et al.,* 2008). In 2005, the International Organization for Standardization (ISO) held an International Workshop Agreement (IWA) on dynamic image safety in Tokyo and reported that more research is needed to determine the causal factors for the VIMS (So and Uijke, 2010).

About 30% of the Chinese population is susceptible to motion sickness (So and Finney *et al.*, 1999). When a stationary viewer is watching compelling moving scene, he or she can report sensation of self-motion illusion (called vection) (Chow *et al.,* 2007). Vection has been found to be correlated with levels of VIMS and postural stability (e.g., Chow *et al.,* 2007; Hettinger *et al.,* 1992; So *et al.*, 2002). The correlation between vection and VIMS is consistent with the sensory conflict theory because sickness is generated in a sensory conflict situation where a person is reporting illusion of self-motion while remain physically stationary (Reason, 1978). The reported correlation between vection and VIMS has led to the term 'vection induced motion sickness' (Hettinger *et al.,* 1992).

In 1994, Ebenholtz and his colleagues proposed a theory to link VIMS with inappropriate eye movements (Ebenholtz *et al.*, 1994). This theory is consistent with the findings that suppression of eye movements by fixation can significantly reduce levels of VIMS (Stern *et al.,* 1990; Webb and Griffin, 2002). Ebenholtz hypothesized that the afferent signals in the ocular muscles will trigger vagal nuclei, resulting in a range of sickness symptoms associated with the autonomous nervous systems - the nystagmus theory. Because eye movements follow foveal stimulation and vection follows peripheral stimulation (Brandt et al., 1973), the nystagmus theory indicates that in the presence of foveal stimulation, sickness will correlate with eye movements but not necessarily with vection. Since then, there have been competing studies reporting the decoupling between vection and VIMS (Webb and Griffin, 2002, 2003) as well as coupling between vection and VIMS (Chen *et al.*, 2011; Flanagan *et al.,* 2002; Lo and So, 2001).

A Hypothetical Theory for The Effects of Eye Fixation on VIMS

When watching a moving visual stimulus, our eyes will voluntarily follow the moving stimulus. This is referred as optokinetic nystagmus (OKN). This type of eye reflex movement is characterized by a slow phase eye movement following the stimulus and a fast saccadic eye movement to reset the eye positions. Depending on the velocity of the stimulus, the slow phase OKN velocity can match about 30% to 70% of the velocity of the stimulus (Koenig *et al.*, 1978). This will cause a reduction in the peripheral retinal slip velocity of the stimulus. While watching a moving stimulus, eye fixation will result in both (i) the suppression of eye movement and (ii) the increase in peripheral retinal slip velocity of the moving visual stimulus. Consequently, the significant reduction of VIMS due to eye fixation can due to either (i) the suppression of the OKN; or (ii) the increases in peripheral retinal slip velocity; or (iii) both. Because changes in peripheral retinal slip velocity have been shown to affect the levels of VIMS and vection (Hu *et al.*, 1989), if the effects of eye fixation are proven to be due to the increases in peripheral retinal slip velocity, it will provide much support to the sensory conflict theory which predicts that VIMS is associated with vection. On the other hand, if the effects of eye fixation are shown to have due to the suppression of OKN alone, it will provide much support to the nystagmus theory. Currently, the belief is that the effects of eye fixation are due to the suppression of the eye movement. Hu *et al.* (1989) reported that when watching striped patterns rotating at 60 degrees per second (dps), increasing the rotating velocity from 60 dps to 90 dps reduced the levels of VIMS. On the other hand, reducing the rotating velocity of the moving pattern from 60 dps to 15 dps also reduced the levels of VIMS. In other words, levels of VIMS peaked when the moving striped patterns were rotating at 60 dps. Participants in Hu and his colleagues' study did not fixate their eyes. We know that if a participant watching patterns rotating at 15 dps and 60 dps were to fixate their eyes on a pointer, the peripheral retinal slip velocities of the stimuli would increase. According to Hu *et al.* (1989)'s result, increasing the peripheral retinal slip velocity of patterns rotating at 15 dps and 60 dps would cause sickness levels to increase (for the 15 dps condition) and decrease (for the 60 dps condition), respectively. In other words, when watching patterns rotating at 15 dps, increases in peripheral retinal slip velocity associated with eye fixation can increase levels of VIMS. In this study, we hypothesize that the effects of eye fixation on VIMS is mainly due to the increases in peripheral retinal slip velocity when watching patterns rotating at 7 dps. We used 7 dps because it was the lowest speed that our system could achieve and we would like to test the extreme range.

Objectives and Hypotheses

The objective of this study is to test whether the effects of eye fixation on VIMS are primarily due to the suppression of eye movement or the increases in peripheral retinal slip velocity of the visual stimulus. The logics and reasoning for the hypotheses are explained in the previous section. In this study, we test the following hypotheses: (i) after watching striped patterns rotating at 7 dps for 20 minutes, viewers will reported significantly increases in levels of VIMS (H1); (ii) when watching striped patterns rotating at 7 dps, eye fixation will increase the peripheral retinal slip velocity (H2a) and increase the levels of VIMS (H2b); (iii) after watching striped patterns rotating at 60 dps for 20 minutes, viewers will reported significantly increases in levels of VIMS (H3); and when watching striped patterns rotating at 60 dps, eye fixation will increase the peripheral retinal slip velocity (H4a) and reduce the levels of VIMS (H4b).

Hypotheses H3 and H4 are consistent with the previous findings while hypotheses H1 and H2 are the new hypotheses that eye fixation can increase the levels of VIMS. Hypotheses H1 and H3 were needed to justify that the stimulus were strong enough to cause VIMS.

METHOD

Stimuli and Apparatus

Black-and-white striped patterns similar to that used in Hu *et al.* (1989) were digitally reproduced and projected on a home developed three-screened projection system (Figure 1). This system was used in previous studies of VIMS (Chow *et al.,* 2007; Ji *et al.,* 2007, 2009). The projected patterns spanned 210 degrees horizontally and 55 degrees vertically. In this study, the patterns were set to rotate in yaw axis at 7 dps and 60 dps. The former is the slowest speed that the system could achieve by shifting the pattern by pixel per frame and the 60 dps was chosen because Hu *et al.* (1989) reported that the highest levels of VIMS was reported with this speed of rotation (see section entitled 'objectives and hypotheses'). In this study, the positions of retinal images of the patterns respond instantly to eye and head movements. This is important as any response delays commonly found in head-tracked virtual reality (VR) system can significantly affect subjective ratings subsequently taken (So and Griffin, 1991, 1992, 1995, 2000; So and Chung e*t al.*, 1999).

During each session, standing participants were required to place their heads on a chin-rest and put their arms around a rigid stand (Figure 2). The use of chin-rest to restrain the head position was needed to minimize the influence of head movement on VIMS (Stoffregen and Smart, 1994). Similarly, the requirement for the participants to put their arms around a rigid stand was to minimize any postural motion.

The projection room was air-conditioned and during the exposure, all light was turned off except that from the stimulus. The participants' eye movements were measured using electrooculography (EOG) with the MP150 system from BioPac Inc. Before each session, five electrodes were placed on the face of the participant (Figure 2). One was put on the forehead, two were put on the temple regions and two were put on the upper and lower side of their dominant eyes. An illustration of how the electrodes were located on the face can be found in Figure 2. The one on the forehead was used to collect the ground signal. The two on the temples were used to collect EOG signals associated with horizontal eye movements and the two on the upper and lower side of the dominant eye were used to collect the vertical eye movements of the participants. After the EOG electrodes were in placed, a calibration procedure was conducted to obtain the mapping constants in degrees per voltage in order to transform the EOG signals to degrees.

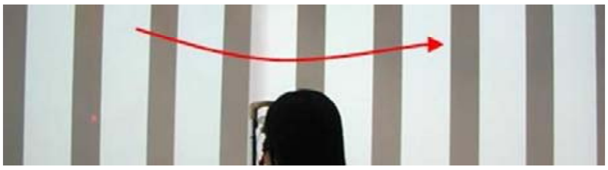

Figure 1. An snap-shot showing the black-and-white striped stimulus (210 degrees horizontally and 50 degrees vertically) display system (adopted from Ji *et al.*, 2010)

Figure 2. A photograph showing a viewer resting her head on a chin-rest and a rigid stand while wearing the EOG electrodes for eye movement measurements.

Design of Experiment

The experiment used a within-subject full factorial design with four conditions which were the exhaustive combinations of two rotating velocity (7 and 60 dps) and with and with eye fixation. Nine participants aged from 23 to 28 (4 male and 5 female) took part in all four conditions with at least one week separation between exposure. The orders of exposing to the four conditions were randomized. They were either with normal eye sight or corrected eye sight. They all attained a 20/20 visual acuity or better. Before the experiment, they were informed about the general aim of the study but they were not told the specific objectives and hypotheses. They needed to complete a pre-exposure simulator sickness questionnaire (SSQ: Kennedy *et al.,* 1993) after the EOG calibration and before the start of the 20 minute exposure. Should a participant report a total pre-exposure SSQ total score of 10 or more, he or she will be asked to rest for 5 minutes and fill in another pre-exposure SSQ. If the total score is still great than 10, he or she will be asked to come back on another date. During the exposure, rated levels of nausea were measured using a 7-point nausea rating adopted from Golding and Kerguelen (1992) at every two minutes (Table 1). Rated levels of vection were also collected. The rating allowed a participant who reported moderate nausea to quit the experiment. One participant reported a level of 6 after 16 minutes. She quitted the experiment and completed a post-exposure SSQ. Her ratings at 18 and 20 minutes were assumed to be ‘6’ as well. After the exposure, all participants filled in a post-exposure SSQ. The experiment was approved by the Human Subject Experiment of the Hong Kong University of Science and Technology.

Table 1. The 7-point nausea rating scale (adopted from Golding and Kerguelen, 1992).

0	No symptoms
1	Any unpleasant symptoms, however slight
2	Mild unpleasant symptoms (e.g., stomach awareness, sweating but no nausea)
3	Mild nausea
4	Mild to moderate nausea
5	Moderate nausea but can continue
6	Moderate nausea, want to stop

RESULTS

Although the distribution of the nausea data followed the normal distributions ($p > 0.1$: Kolmogorov-Smirnov), both SSQ data and data collected within a single condition did not followed the normal distributions. Non-parametric statistical tests were used to analyze the data.

Effects of exposure duration

As the exposure duration increased, the levels of nausea ratings increased significantly ($p < 0.001$, Friedman two-way ANOVA test). Results of Wilcoxon signed ranked test indicated that the post-exposure SSQ total scores were significantly higher than the pre-exposure SSQ total scores for all of the four conditions ($p < 0.01$). This suggests that the stimuli were strong enough to cause significant increases in levels of VIMS among the viewers. The results support both hypotheses H1 and H3.

Effects of Visual Stimuli Velocity

Significantly higher levels of nausea were reported with patterns moving at 60 dps than patterns moving at 7 dps ($p < 0.01$, Wilcoxon). Two-way interactions were observed between the effects of exposure duration and the effects of stimulus velocity. Investigation of the interaction plots indicated that at 60 dps conditions, nausea increased at faster rates than at 7 dps conditions. The significant effects of stimulus velocity were consistent with the findings of Hu *et al.* (1989) and it supported the hypothesis that in the presence of eye movement, increases of peripheral retinal slip velocity of moving stimulus can significantly increased levels of VIMS.

Effects of Eye Fixations

Overall, eye fixation had significant main effects on levels of nausea (*p < 0.01*, Wilcoxon). When the patterns were moving at 60 dps, eye fixation significantly reduce the levels of nausea. This is consistent with the findings of Webb and Griffin (2002). Measurements of EOG indicated that the mean peripheral retinal slip velocity increased from 35 dps to 60 dps with eye fixation. This supported hypotheses H4a and H4b.

When the patterns were moving at 7 dps, eye fixation increased the average levels of nausea from 2.1 to 2.3 but the difference was not statistically significant. Data collected from the EOG measurements indicated that the peripheral retinal slip velocity significantly increased from 2.6 dps to 7 dps with eye fixation. This supported hypothesis H2a.

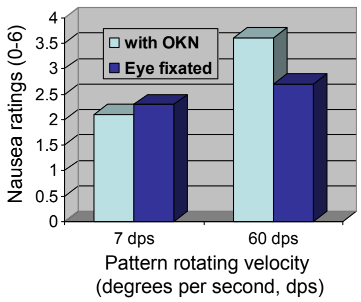

Figure 3. Average nausea ratings as function of pattern rotating velocity and eye fixation condition.

DISCUSSION

The main finding of this study is that when patterns were moving at 7 dps, eye fixation significantly increased the peripheral retinal slip velocity of the patterns (*p < 0.01,* Wilcoxon) and slightly increased the mean levels of nausea although the increases were not statistically significant. The lack of significance might have due to a competing effect of eye movements. It could have been that with eye fixation, the suppression of eye movement caused an reduction in levels of nausea while the increases in peripheral retinal slip velocity caused an increase in levels of nausea. When the two opposite effects were combined, the resulting changes in levels of nausea become not significant. It is worth mentioning that at 60 dps condition, eye fixation significantly reduced the levels of nausea but such reduction could not be repeated at 7 dps conditions. As the effects of exposure duration significantly increased the levels of nausea in all four conditions, the lack of reduction of sickness with eye fixation at 7dps deserve further research. In order to test the above hypothetical consideration, one needs to isolate the effects of eye movement suppression from changes in peripheral retinal slip velocity.

CONCLUSIONS AND FUTURE WORK

Eye fixation has consistently been shown to significantly reduce levels of visually induced motion sickness (VIMS). The common belief is that the reduction in VIMS is associated with the suppression of eye movement. This study proposed an alternative theory to associate the reduction of VIMS due to eye fixation with the increases in peripheral retinal slip velocity. Results showed that when participants were watching striped patterns rotating at 7 dps, eye fixation significantly increased the peripheral retinal slip velocity from about 2.6 dps to 7 dps and but failed to cause a significant change in the average rated levels of VIMS. However, in the same study, increasing the peripheral retinal slip velocity of moving patterns from 2.6 dps to 35 dps in the presence of OKN significantly increased the rated levels of nausea from 2.1 (mild unpleasant symptom) to 3.6 (mild to moderate nausea). It might be that when watching patterns moving at 7dps, eye fixation introduced two competing effects: (i) suppression of eye movement reduced levels of VIMS and (ii) increases in peripheral retinal slip velocity increased levels of VIMS. Current results indicated that the two opposite effects had similar strength. Since the two competing effects are associated with two competing theories of VIMS (the sensory conflict theory and the nystagmus theory), further studies are desirable. Understanding the relationship between suppression of eye movements and changes of retinal slip velocity on VIMS can help simulator designers to develop measures to reduce levels of simulator sickness among the viewers.

This study only used nine participants. Future studies should use more participants and also used Latin square to balance the order of presentation rather than randomization because of the small number of participants. In order to increase the strength of the stimuli, future studies should consider using stimuli of longer duration. In this study, although a chin-rest was used to restraint the head position, future studies should monitor and measure the positions of participants' heads and upper bodies.

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