Comparing Symptoms of Visually Induced Motion Sickness Among Viewers of Four Similar Virtual Environments with Different Color

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Abstract. This paper reports an experiment conducted to study the effects of changing scene color inside a virtual environment on the rated levels of nausea among sixty-four viewers. Current theory on visually induced motion sickness suggests that changing the color of dynamically moving visual stimuli, while keeping everything equals, will not affect the rated sickness symptoms of the viewers. Interestingly, a recent study by another authors reported that color do affect levels of visually induced motion sickness. Preliminary results of this experiment suggest that while exposure duration to the visual stimuli significantly increased the rated levels of nausea and simulator sickness questionnaire scores (*$p<0.001$, ANOVAs*), changes of color did not affect the levels of sickness. Reasons for the conflicting results are discussed in the paper.

1 Introduction

Occurrence of visually induced motion sickness (VIMS) has been associated with the presence of visually induced self-motion illusion (vection) in the absence of appropriate vestibular stimuli and / or responses. One example is to visually navigate through a virtual environment (VE) while sitting stationary. It is well known that the perception of visual motion in human follows the magnocellular visual pathways that involve m-type (or parasol) ganglion cells that are color-blind (the two visual systems theory: Schneider, 1967). This suggests that, giving all things equal, changing the color of objects inside a VE but keeping the same contrast ratios and luminance (or gray scale) levels will not affect the reported symptoms of the viewers. With much interest, the authors read Bonato *et al.* (2004) which reported that color of the visual stimuli can affect symptoms of VIMS. Does this imply that the traditional association between the magnocellular visual pathways and VIMS has been mistaken? An experiment has been conducted to investigate the effects of changing color of objects inside a VE on symptoms of VIMS among sixty-four viewers.

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2 Objectives and Hypothesis

The objective of this experiment was to study whether rated levels of visually induced motion sickness (VIMS) associated with a virtual reality (VR) simulation would change when the color of that corresponding VE was changed. We hypothesize that color would have no significant influence on the rated levels of VIMS (H1). This hypothesis is consistent with the two visual systems theory by Schneider (1967) that states that the ambient vision, which is responsible for detecting motion, is insensitive to color.

3 Methods and Design

3.1 Manipulation of Color While Keeping Other Things Equal

A full-factorial between-subject design was used. The color of the virtual environments (VEs) was the only independent variable and had four levels: (i) blue-colored sea with brown-colored floor; (ii) green-colored sea with brown-colored floor; (iii) blue-colored sea with gray-colored floor; and (iv) green-colored sea with gray-colored floor (snap-shots of these four VEs will be shown during the presentation at the conference). The Paint Shop Pro® version 6 was used to manipulate the color. The color of the sea and the ground were manipulated because they occupied about half of the field-of-views during the VR simulation. The sky also occupied a large portion of the field-of-view but it was difficult to change the blue sky to another natural color (e.g., cloudy white) without affecting the spatial frequencies. In this study, we avoided unnatural combinations of color (e.g., red sea and a green sky). The four VEs have been carefully manipulated to produce similar spatial frequencies (their spatial frequencies were not significantly different using t-tests: $p>0.9$). To calculate the spatial frequencies, 4800 snapshots (2 snapshots per second) were taken from each of the four VR simulations. These snapshots were captured at a resolution of 495 pixels (horizontal) x 115 pixels (vertical) to match the resolution of the VR4 head-mounted display (HMD) used in the study. An image analysis of these 4800 snapshots shows that the views of the sea and the ground occupy an average of about 28% of the total field-of-view. To facilitate spatial frequency estimation, these snapshots were converted to portable gray map (pgm) files according to Hoffmann (2005).

The average radial spatial frequency of each group of 4800 snapshots taken from the same VR simulation was then calculated using the ‘combined’ method adopted from So, Ho and Lo (2001). This published method is also illustrated and explained at www.cybersickness.org. The experiment had thirty-two male and thirty-two female Chinese participants between 19 and 27 years old. They were randomly assigned to one of the four VEs so that each VE was viewed by eight male and eight female participants. All participants were healthy. A color blindness test was conducted before the experiment to ensure they did not have color blindness. They were paid US$6 per hour to compensate for their time and travel expenses. The experiment was approved by the human subject committee of the Hong Kong University of Science and Technology.

3.2 Measurements

A 7-point nausea rating scale was used to measure the level of nausea (Golding and Kerguelen, 1992; Webb and Griffin, 2002) and a four-point vection rating scale was used to measure the level of self-motion (Hettinger et al., 1990). Both scales have been used in previous studies of VIMS (So, Ho and Lo, 2001; So, Lo and Ho, 2001). In addition, the 27-symptom simulator sickness questionnaire (SSQ) was also used (Kennedy et al., 1993). Data from the pre-exposure and post-exposure SSQs were used to calculate the nausea sub-score (N), oculo-motor sub-score (O), disorientation sub-score (D) and the total SSQ score (TS). Besides subjective measures, objective postural tests were used to quantify the ability of participants to balance themselves before and after VR exposures. In this study, the sharpened Romberg (also known as the tandem Romberg) (e.g., Hamilton *et al.,* 1989; Cobb and Nichols, 1998), the stand-on-preferred-leg (SOPL), and the stand-on-non-preferred-leg (SONL) (e.g., Kennedy *et al.*, 1997) tests were used. In all three tests, the durations that participants could balance themselves without changing the required posture were measured (referred to as the balancing time) as well as the amount of head sway (Kennedy and Stanney, 1996).

3.3 Procedures

A Virtual Research VR4 LCD Head-Mounted Display (HMD) with a field-of-view of 48º × 36º was used to present the virtual environments. This HMD has a resolution of 495 pixels (horizontal) × 115 pixels (vertical). VR simulations were rendered by the dVISE software running on a Silicon Graphic ONXY II Infinite Reality workstation at a frame rate of 30 frames per second. A Polhemus 3-Space magnetic tracker was used to measure the head position and orientation during the VR simulation as well as during the postural tests.

Before the experiment, all participants were educated on the meaning of vection and the meanings of the symptoms used in the SSQ. After that, they were given three minutes to try out the VR apparatus and to personalize the adjustment of the apparatus before they were asked to fill in a pre-exposure SSQ. If the participants had a total score of 10 or more (corresponding to more than one slight sickness symptom), they were asked to rest in an air-conditioned room for 10 minutes and to complete the pre-exposure SSQ again. If their scores were still 10 or more, they were asked to come back on a later date. This practice is consistent with that of Stanney *et al.* (2003). After the pre-exposure SSQ, participants had to carry out four trials of sharpened Romberg tests followed by three trials of SOPL and SONL tests. They would then be assigned randomly to one of the four VR simulation conditions. The exposure time was 40 minutes. During the exposure, participants viewed the VE through the HMD and they were navigated along a pre-determined path inside the VE. The same path was used for all participants and they could change their viewpoints by turning their heads although participants were asked to keep their heads facing forward unless they were instructed otherwise. To encourage the participants to be more attentive, they were asked to turn their heads to one side every 30 seconds and to report verbally what they saw. The direction of turning was randomized. This method to encourage involvement was adopted from So, Lo and Ho (2001). During the 40-minute exposure and at every 5-minute interval, participants were asked to rate their nausea feelings verbally according to a 7-point nausea rating (0 to 6) and their feeling of self-motion according to a 4-point vection rating (0 to 3). After the exposure, participants completed a post-exposure SSQ and performed another four trials of sharpened Romberg tests followed by three trials of SOPL and SONL tests. Participants who gave a rating of 6 on the nausea scale (i.e., moderate nausea and want to stop) were allowed to terminate their exposure and complete the post-exposure SSQ and the postural tests. We assumed that the nausea and vection ratings of these subjects remained the same for the time beyond their termination time. In other words, if a participant scored a rating of 6 on the nausea scale and a rating of 2 on the vection scale after 30-minute exposure, the estimated nausea and vection ratings at 35 minutes and beyond would be 6 and 2, respectively.

4 Results and Discussion

The data followed a normal distribution. Preliminary results of ANOVAs indicate that exposure duration had significant effects on both nausea and vection ratings ($p<0.001$). However, both color and gender did not significantly affect the nausea and vection ratings ($p>0.1$). Student-Newman-Keuls (SNK) tests showed that nausea ratings increased significantly from 0 minutes to 25 minutes and did not change significantly from 25 minutes to 40 minutes.

The simulator sickness questionnaire (SSQ) total scores taken after the exposure (i.e., post-SSQ scores) were significantly greater than those scores taken before the exposure (i.e., pre-SSQ scores) ($p<0.01$). For each participant, the differences between the post-SSQ scores and the pre-SSQ scores were the differences between the corresponding post-exposure scores and the pre-exposure scores. Results of ANOVAs show that color had no significant effect on the differences between the post- and the pre-SSQ total score ($p>0.3$). Both the balance times and the root-mean-square (r.m.s.) head deviations during the balancing periods of the postural tests along the six directions (fore-and-aft, lateral, vertical, roll, pitch and yaw) were analyzed. Results of ANOVAs indicate that the r.m.s. head deviations along yaw and roll axes collected from the sharpened Romberg tests and r.m.s head deviations along pitch axis collected from the SOPL tests collected after the exposure were significantly greater than those collected before the exposure ($p<0.05$). However, these significant increases due to exposure to the VR simulation were not significantly affected when VEs with different color combinations were used ($p>0.05$).

The preliminary results of this experiment clearly support hypothesis H1 that the rated levels of VIMS of participants navigating through a VE will not be affected when its color is changed while keeping a similar level of average spatial frequencies. In this study, the change of color was limited to the choices of natural color (e.g., blue or green for the sea).

The current findings contradict with the results of Bonato *et al.* (2004). Further analyses reveal that in Bonato's study, effects of color were significant on rated levels of headache but not on rated nausea. Also, the methods to manipulate the color of the visual stimuli in the two studies are very different. For example, in Bonato's study, the comparison was conducted between conditions with and without color while in the current study, the comparison was conducted among conditions with different colors. Another reason for the differences in the results of the two studies may be due to the differences in the portion of the field-of-views in which the changes of color had occurred.

5 Conclusions

Viewing a 40-minute dynamically moving virtual reality (VR) simulation significantly increased the rated levels of nausea ($p<0.001$), vection ($p<0.001$), and SSQ scores ($p<0.05$) among sixty-four viewers.

Measures of head deviations during sharpened Romberg tests and Stand-on-Preferred-Leg tests conducted after the 40-minute VR exposure were significantly greater than those measured before the exposure ($p<0.05$).

While the 40-minute VR exposure could significantly increase both the rated levels of sickness and postural stability as measured by head deviations, changing the color of the virtual environment by about 28% did not affect the rated levels of sickness nor postural stability measurements.

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