Effects of foveal retinal slip on visually induced motion sickness: a pilot study

Guo, C.T.[1], So, R.H.Y.[1*]
[1] Department of Industrial Engineering and Logistics Management, the Hong Kong University of Science & Technology
[*] corresponding author: ctguoust@ust.hk

This experiment isolated and studied the effects of eye motions on visually induced motion sickness (VIMS) from the effects of foveal retinal slip velocity on VIMS. Eye motion has been shown to contribute to motion sickness. However, most previous work manipulated eye motion using eye fixation pointer. In so doing eye motion suppression was co-founded with increase in the relative velocity between the eyes and the visual stimulus (retinal slip velocity). Retinal slip is a necessary condition in perception of visual motion and could affect VIMS. However, due to difficulties in controlling eye motion in isolation of retinal slip, few work examined this topic. Guo *et al.* (2011) studied the effect of eye motion by controlling retinal slip velocity and showed that eye motion can still have significant effects on VIMS after retinal slip velocity is controlled. In this study, four conditions represent the factorial combinations of high (+) and low (-) levels of eye motions (EM) and foveal retinal slip velocity (FRSV). Peripheral retinal slip velocity was kept the same throughout the four conditions. A real time eye-slaved pointer was used to achieve the design and presentation of the conditions. Eight subjects participated in the experiment and within subject design was used. Results of Wilcoxon signed rank tests on preliminary data indicated that reduction of foveal retinal slip while keeping eye movements and peripheral retinal slip the same can significantly reduce levels of VIMS (post-exposure total simulator sickness questionnaire scores: $p < 0.02$ and 7-point nausea ratings: $p < 0.05$). Implications of these preliminary results are discussed in the paper.

INTRODUCTION

Background

Motion sickness can be characterized by a series of symptoms like nausea, sweating, vomiting, dizziness, etc (Ji *et al.,* 2005; Lo and So, 2001; Kennedt *et al.*, 1993; So and Ujike, 2010). About one third of Chinese are susceptible to motion sickness (So *et al.,* 1999). Many circumstances in daily life can provoke motion sickness. Examples include sitting in a moving vehicle as a passenger, playing computer games, or watching IMAX movie. It is widely accepted that motion sickness are related to vestibular systems (Reason, 1978). In particular, vestibular responses such as Optokinetic Nystagmus (OKN) are related to VIMS (Elbenholtz *et al.*, 1994; Guo *et al.*, 2011). The mechanism of motion sickness has been studied for more than a decade and the most widely accepted theory for motion sickness is the sensory conflict, or sensory rearrangement theory (Reason, 1978). This theory explains that "it is the conflict among signals from different receptors, or the conflict between current and expected receptor input that produce motion sickness" (quoted from Reason, 1978). Reason proposed that both the visual and vestibular systems are involved in the sensory rearrangement process. In this study, we will examine the effects of foveal retinal slip velocity (a visual stimulus parameter) in isolation of eye movements (a vestibular response). So *et al.* (2001) reported that as the foveal retinal slip velocity increased, the levels of VIMS increased but eye movements were not controlled in that study.

Possible role of Foveal Retinal Slip on VIMS and methods to manipulate eye movements and foveal retinal slip insolation

Eye motion has been theoretically proposed and empirically verified to be an important factor associated with generation of visually induced motion sickness (Ebenholtz *et al.*, 1994; Ji *et al.*, 2009; Stern et al., 1990; Webb and Griffin, 2003; Yang *et al. 2011*). Ebenholtz and his colleagues predicted that abnormal eye muscle traction can provoke VIMS. In previous studies investigating the role of eye motion in VIMS, eye fixation pointers were used to suppress eye motion in order to compare conditions with and without eye motion. In so doing, foveal retinal slip was also suppressed. Consequently, when Stern *et al.* (1990) reported that eye fixation reduce motion sickness, it could be the reduction of foveal retinal slip that had contributed part of the reduction in VIMS.

Foveal retinal slip occurs when projections of a visual target on the retina cannot be completely stabilized by ocular reflex (e.g., OKN or vestibular ocular reflex: VOR). Central vision represents our visual attention and ocular reflex enables our gazes to following moving objects so that we can perceive the objects clearly. When we are exposed to moving environment, OKN enable our eyes to following the projections of the moving environment. However, OKN gains are not unity and discrepancy causes foveal retinal slips. Aaccording to the sensory rearrangement theory (Reason, 1978), pro-long exposure to foveal retinal slip could be a factor that contributes to VIMS. Chen and Stoffregen in 2011 found that motion sickness of passive game players are higher

 DOI 10.1177/1071181312561533

than active players. One possible explanation is that during active game playing, subjects performed more effective target pursuit than passive game playing. The former may result in lesser foveal retinal slip. To illustrate the logics, imagine the case when subjects know where the target is going and the case when subjects are not aware of the direction of the target, foveal retinal slip should be higher in the second case.

Ji *et al.* (2009) studied the role of eye motion in VIMS in terms of changes in foveal and peripheral retinal slip under the absence of vection. Her results were consistent with Stern *et al.* (1990)'s findings that eye fixation could reduce foveal retinal slip to zero and could significantly reduce VIMS at the same time. Ji and her colleagues also proposed that foveal retinal slip is more important than peripheral retinal slip when vection is purposely suppressed. In 2011, this author found that eye motions can still increase VIMS when peripheralretinal slips had been controlled (Guo *et al.*, 2011). However, in that study, only peripheral retinal slip was controlled and foveal retinal slip was cofounded with eye motion. In 2011, Yang studied effects of voluntary and involuntary eye motion on eye motion. In his experiment, due to limitation of apparatus, foveal region was not completely blocked, and difference between high and low level foveal retinal slip velocity was not large enough to generate a significant effect on VIMS (Yang *et al.,* 2011).

In summary. a review of literature indicates that in most studies on the effects of eye movements on VIMS, retinal slip coexisted with eye motion and they were cofounded factors; therefore effect of foveal retinal slip on VIMS in isolation of eye motion is still not clear. So far, a study to isolate eye movement from foveal retinal slip could not be found. One possible reason may be due to the technical difficulty in controlling eye motion and manipulating foveal retinal slip velocity at the same time. In our experiment, a moving cross was used to guide subjects' gaze angles, while at the same time, an eye slaved panel was used to block subjects' central vision to suppress foveal retinal slip velocity to zero. Using this methodology, patterns of eye motions having similar slow and fast phase velocities and magnitudes similar to OKN could be generated but with zero foveal retinal slip velocity.

Objectives and Hypothesis

The objective of our study was to isolate the effects of foveal retinal slips (FRSs) and the effects of eye motions (EMs) under controlled peripheral retinal slips. We hypothesized that when eye motions are the same, conditions with foveal retinal slip would produce higher VIMS than condition with zero foveal retinal slip (i.e., the FRS hypothesis). When FRSs are the same, either zero or non-zero, conditions with larger eye motions would produce higher levels of VIMS than conditions with no eye motion (i.e., the EM hypothesis).

METHODS

Participants

Eight viewers, 4 males and 4 females, with ages from 21 to 24 participated the experiment. All of them were students at the Hong Kong University of Science and Technology. They were tested to have normal or corrected-to-normal visual acuity. Subjects' written consents were obtained and they received a compensation of HKD50 (about USD6) per hour for their time. The experiment was approved by the Human and Ethics Committee at the Hong Kong University of Science and Technology.

Materials and Apparatus

A virtual optokinetic drum with vertical black and white stripes was used to present the visual stimuli (Figure 1). This drum was frequently used in previous studies (Ji *et al.*, 2009; Guo *et al.,* 2011; and Yang *et al.*, 2011). Eye motions in horizontal and vertical direction were recorded both by EOG 100C BIOPAC® and an infra-red camera system VT1 by EyeTech Ltd. The former was used because previous studies also used the EOG to measure the OKN patterns and the authors would like to stay consistent. The latter was used to drive an eye-slaved elliptical panel to block subjects' central vision so as to obtain a zero foveal retinal slip velocity. Participants were instructed to keep their heads stationary using a chin rest. To prove that subjects' heads were kept stationary, head motion was recorded by a video recorder and body vibration was recorded by the FASTRAK system from Polhemus. We could put a Polhemus tracker on subjects' heads but it was decided not to because subjects' heads already were instrumented with EOG electrodes and wearing a cap mounted with the Polhemus tracker made things too complicated. Through out the experiment, the heads of the participants remained stable and not moving.

The virtual optokinetic drum was made of an 183cm × 460cm curved wide-angle screen with three projectors (Figure 1). As illustrated in Figure 1, a viewer standing at the centre of the curved screen will have a 206° (1800 pixels) horizontal field of view of the projected visual stimuli. In this study, the visual stimulus was vertical black and white stripes moving along yaw direction from left to right. The view angle of one black stripe and one white stripe summed up to approximately 15° (133 pixels) with 5.72° (83 pixels) for black stripe and 9.5° (50 pixels) for white stripe (cf. Stern *et al.* 1990; Ji *et al.*, 2009). The differences in widths for the clack and white stripes were to cancel out the average perceived differences (Stern *et al.*, 1990).

Experimental Design

The experiment was a 2×2 full factorial within-subject design. Independent variables were eye motion (+, with eye motion; -, without eye motion) and foveal retinal slip velocity (+, foveal retinal slip velocity is around 15°/s; -, foveal retinal slip is 0°/s). Details about every condition are illustrated in Table 1: condition A (eye motion: +, foveal retinal slip: -), condition B (eye motion: +, foveal retinal slip: +), condition C (eye motion: -, foveal retinal slip: -), condition D (eye motion: -, foveal retinal slip: -).

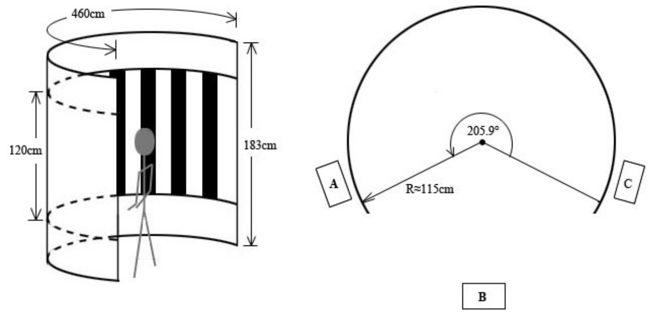

Figure 1: Illustrations of the virtual optokinetic drum. The left diagram is a 3D view and the right diagram is the top view. A, B and C illustrate the locations of the three projectors.

In this study, levels of VIMS were measured by 7-point nausea ratings (Golding and Kerguelen, 1992), nausea ratio scale data using free modulus magnitude estimation (McGee, 1998) and Simulator Sickness Questionnaire (Kennedy *et al.*, 1993; Ji *et al.*, 2009; Kennedy *et al.*, 2010). Vection rating scale data (Webb and Griffin, 2003) were also taken. These were the dependent variables.

Procedure

Two 4×4 Latin Square designs were used to balance the presentation of the conditions among the eight subjects. All consecutive conditions were separated by at least 7 days to avoid adaptation (c.f., Ji *et al.*, 2009). Before the experiment, the subjects were asked to read the instructions for the experiment and sign the consent form. A line length estimation test was conducted to ensure the subjects could use a ratio scale. Twenty lines segments with different lengths from 1cm to 20cm were implemented to provide familiarity with the free modulus magnitude estimation method. In order to indicate the susceptibility to motion sickness of each subject, the subjects completed a motion sickness susceptibility survey questionnaire and an MSSQ-short questionnaire (Golding, 2006). After becoming familiar with the literal meanings of various VIMS symptoms, subjects completed a pre-exposure Simulator Sickness Questionnaire (pre-SSQ). After putting on the surface EOG electrodes and the FASTRACK sensor, all subjects would go through calibration trials to obtain their personalized EOG mapping constants for that condition. After that, the subjects rested for 5 minutes with their eyes closed.

Table 1: Details about the 4 conditions. Keys: 'EM' is eye motion; 'FRSV' is foveal retinal slip velocity; 'BV' is background velocity; 'CV' is central / visual target velocity; 'PRSV' is peripheral retinal slip velocity. 'SPV' is slow phase velocity of Optokinetic Nystagmus (OKN). EM and FRSV were independent variables and PRSV was the control variable. Both EM and FRSV were manipulated by BV and CV, and they were estimated by pilot tests' results before the main experiment. In condition A, subjects' eyes were guided by a gray moving cross to produce the same eye motion as condition B, while foveal region was blocked by a black eye-slaved ellipse panel. In condition C, eye motion was totally suppressed by stationary eye fixation (a gray cross in an dark ellipse with the same size in condition A and B). In condition D, eye motion was suppressed by restricted field of visual focus. Inside the restricted field (an ellipse with the same size as eye slaved ellipse in condition A), gray and white stripes moved at 25°/s and the SPV was slow (7~10°/s). More than 60% reduction in eye motion magnitudes were obtained as compared with conditions A and B.

Con	EM	FRSV °/s	BV °/s	CV °/s	PRSV °/s
A	+ SPV: 35~40	- 0	50	40	15
B	+ SPV: 35~40	+ 10~15	50	--	15
C	- SPV: 0	- 0	15	0	15
D	- SPV: 7~10	+ 15~18	25	25	15

In the main test, subjects were exposed to four 30-minute conditions of watching vertical stripes rotating in yaw axis in four separate weeks. Details of the four exposures are illustrated in Table 1. The use of a moving cross to control the eye movement and the use of an eye-slaved panel to block the central vision (and reduce the foveal retinal slip to zero) are also explained in the caption of Table 1. During each 30-minute exposure, subjects were asked to report their subjective nausea severity level using the free modulus magnitude estimation and a 7-point nausea rating scale every two minutes. Levels of rated vection were also obtained at the same time. Immediately after finishing the main test, subjects were asked to complete a post- exposure Simulator Sickness Questionnaire (post-SSQ).

RESULTS

Eye Motion Data

Since both the eye motion and slow phase velocity (SPV) and foveal retinal slip velocity (FRSV) were the independent variables whose values were carefully manipulated in this study, their values in the four conditions needed to be verified. The average SPV in conditions A and B are 29.4°/s and 32.6°/s respectively, with no significant difference ($p>0.05$) by Wilcoxon signed rank test. The lack of significant difference is important as we designed them to be similar. Average peripheral retinal slip velocities in conditions A and B were 20.6°/s and 17.4°/s, respectively, with no significant difference by Wilcoxon signed rank test. Foveal retinal slip velocity in condition A was reduced to zero by eye slaved ellipse panel and in condition B it was 17.4°/s. Eye motions in condition D was verified to be significantly suppressed compared to conditions A and B in terms of SPV. The average SPV in condition D was 8.2°/s, which was significantly lower than those in conditions A and B (p<0.02). Peripheral retinal slip velocities in all four conditions were not significantly different from each other. This verifies that the peripheral retinal slip velocity was controlled to be similar across all conditions. The actual measured parameters for the four conditions are listed in Table 2, which are similar to the designed values listed in Table 1.

Table 2: Actual measured parameters for the 4 conditions. Definition of EM, FRSV, BV, CV and PRSV is stated in the caption of Table 1.

Con	EM	FRSV °/s	BV °/s	CV °/s	PRSV °/s
A	+ SPV: 29.4	- 0	50	40	20.6
B	+ SPV: 32.6	+ 17.4	50	--	17.4
C	- SPV: 0	- 0	15	0	15
D	- SPV: 8.2	+ 16.8	25	25	16.8

Nausea Ratings

The average 7-point nausea ratings obtained during the 30 minutes were 2.9, 3.5, 2.3 and 3.0 in condition A, B, C and D respectively. By Wilcoxon signed rank test, 7-point nausea rating in condition A was significantly lower than that obtained in condition B (p < 0.02, Figure 2). 7-point nausea ratings obtained in condition C was significantly lower than that obtained in condition B (p < 0.05).

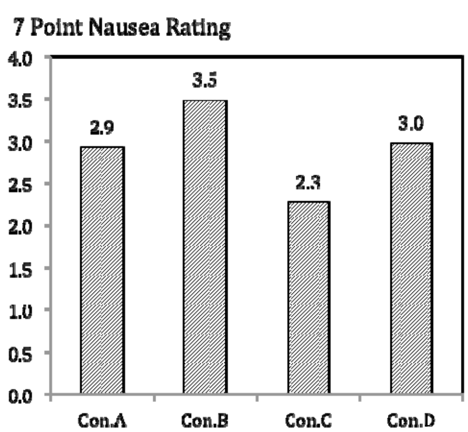

Figure 2: Average 7 point nausea rating of 8 subjects.

Post SSQ scores

The average total post SSQ scores were 66.9, 85.1, 47.7 and 70.1 in conditions A, B, C and D, respectively. By Wilcoxon signed rank test, post total SSQ in condition A was tested to be significantly lower than those obtained in condition B (p < 0.05, Figure 3). Post total SSQ in condition C was significantly lower than that in condition B (p < 0.05). Post SSQ in oculomotor in condition B is significantly higher than that obtained in condition C (p < 0.02).

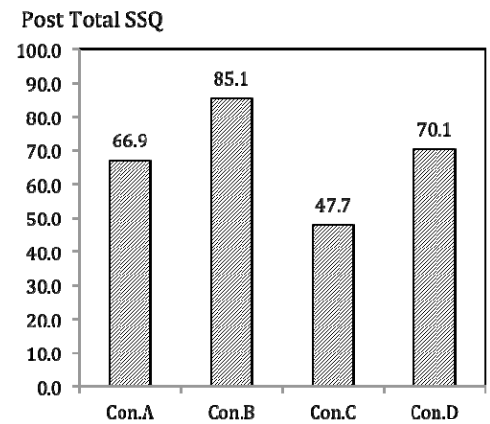

Figure 3: Average post SSQ total score of 8 subjects.

In most conditions, the 7-point nausea rating, post SSQ total score and the free modulus nausea scores were significantly correlated with each other using Pearson correlation tests. However, vection data were not correlated with any nausea data.

CONCLUSIONS AND DISCUSSION

Both 7-point nausea ratings and post SSQ total scores indicated that under the same eye motion conditions as defined in terms of similar SPV and magnitudes, reducing the foveal retinal slip velocity to zero by blocking the central vision can significantly reduce levels of VIMS. These preliminary results support the FRS hypothesis. When eye motions were suppressed, increasing the foveal retinal slip velocity from zero to about 16.8 degrees per second increased the post-exposure SSQ total scores from 48 to 70 and the difference is marginally significant (p=0.09). The authors acknowledge that foveal retina is sensitive to light and colors but not motion, the relationship between foveal retinal slip and VIMS may involve other associated factors. One possible explanation for the results could be that co-founding between the voluntary nature of eye movements (involuntary and voluntary) and foveal retinal slip in this study. Involuntary eye motion had been proposed to produce higher VIMS than voluntary eye motion (Ebenholtz *et al.*, 1994; Yang *et al.*, 2011). Another possible explanation for the role of foveal retinal slip could be its role related to stabilization of visual target on the retina, which helps stabilize posture in an unstable environment. Past studies showed that stationary eye fixation help to stabilize body posture.

In both conditions B and D, foveal retinal slip velocity were high (17.4°/s in B and 16.8°/s in D), but condition B allowed eye motions while eye motions were suppressed in condition D. Although results did not statistically prove the EM hypothesis, where eye motion should produce higher VIMS when foveal retinal slip is in high level, marginally higher mean 7-point nausea rating was observed in condition B than condition D ($p = 0.063$). Further studies with more participants are needed to verify the EM hypothesis.

Our study filled the gap of studying the effects of eye motion and effects of foveal retinal slip on VIMS under the same peripheral retinal slip and in isolation. One possible application of foveal retinal slip could be an indicator of the extent of involuntary eye motions verses voluntary eye motions. Further studies are desirable. Another direction for further studies could be the relationship between foveal retinal slip and body posture or perceived body stability.

ACKNOWLEDGEMENT

The authors would like to thanks the Hong Kong Research Grants Council for partially supporting this study through GRF620009.

REFERENCES

Ebenholtz, S.M. (1992) Motion sickness and oculomotor systems in virtual environments, Teleoperators and Virtual Environments 1(3), 302-305

Ebenholtz SM, Cohen MM, Linder BJ (1994). The possible role of nystagmus in motion sickness: a hypothesis. Aviat Space Environ Med.: 65(11):1032-1035.

Golding J. and Kerguelen M (1992), A comparison of the nauseogenic potential of low-frequency vertical versus horizontal linear oscillation. Aviation, Space, and Environmental Medicine: 63(6): 491-497.

Golding, J. (2006) Predicting individual differences in motion sickness susceptibility by questionnaire, Personality and Individual Differences 41: 237–248.

Guo, C.T., Ji, J.T.T. and So, R.H.Y. (2011) Could OKAN be an objective indicator of the susceptibility to visually induced motion sickness? Proceedings of IEEE Virtual Reality 2011, 19-23 March, Singapore.

Guo C.T., Yang J.X and R.H.Y. So (2011), "The effects of optokinetic nystagmus on visually induced motion sickness after the confounding effects of retinal slip is controlled" i-Perception 2(4) 215.

Hu S, Stern RM, Vasey MW and Koch KL (1989), Motion sickness and gastric myoelectric activity as a function of speed of rotation of a circular vection drum. Aviat Space Environ Med. May, 60(5): 411-4.

Ji, J., So, R.H.Y., Lor, F., Cheung, T.F.R., Howrth, P. and Stanney, K. (2005) A Search for Possible neural pathways Leading to Visually Induced Motion Sickness. VISION, 17, 2, pp.131-134.

Ji, J.T.T., So, R.H.Y. and Chueng, R.T.F. (2009), Isolating the Effects of Vection and Optokinetic Nystagmus on Optokinetic Rotation-Induced Motion Sickness. Human Factors, October 2009 vol. 51 no. 5 739-751.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., and Lilienthal, M. J. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. The International Journal of Aviation Psychology 3(3): 203-220.

Kennedy, R. S., (1986), A review of motion sickness with special reference to simulator sickness.

Kennedy, R. S., Julie Drexler, Kennedy R.C., (2010), Research in visually induced motion sickness. Applied Ergonomics 41 (2010) 494-503.

Lo, W.T. and So, R.H.Y., (2001) Cybersickness in the presence of scene rotational movements along different axes. Applied Ergonomics, Vol.32, No.1, 2001, pp. 1-14.

McGee, M.K. (1998) Assessing Negative Side Effects in Virtual Environments, Ph.D thesis, Industrial and Systems Engineering, Virginia Polytechnic Institute and State University, February 1998, Blacksburg, Virginia

Oman, C.M. (1982), A heuristic mathematical model for the dynamics of sensory conflict and motion sickness, Acta Otolaryngol Suppl 392.

Oman, C.M. (1989), Sensory conflict in motion sickness: An observer theory approach, NASA, Ames Research Center, Spatial Displays and Spatial Instruments 15 p (SEE N90-22918 16-54); UNITED STATES.

Reason, J.T. (1978), Motion sickness adaptation: a neural mismatch model, Journal of the Royal Society of Medicine Volume 71.

So, R.H.Y., Finney, C.M. and Goonetilleke, R.S. (1999) Motion sickness susceptibility and occurrence in Hong Kong Chinese. Contemporary Ergonomics 1999, Taylor & Francis.

Stoffregen, T.A. andSmart, L.J. (1998). Postural instability precedes motion sickness. Brain Research Bulletin, 47, 437−448.

So, R.H.Y., Lo, W.T. and Ho, A.T.K., (2001) Effects of navigation speed on motion sickness caused by an immersive virtual environment. Human Factors, 43, 2001, pp.452-461.

So, R.H.Y. and Ujike, H. (2010) Visually induced motion sickness, visual stress and photosensitive epileptic seizures: what do they have in common? - Preface to the special issue. Applied Ergonomics, 41(4), pp.491-393.

StoffregenT.A. andRiccio, G.E. (1991). An ecological critique of sensory conflict theory of motion sickness. Ecological Psychology, 5, 159−194

Stern, R.M., Hu, S., Anderson, R.B., Leibowitz, H.W. and Koch, K.L. (1990), The effects of fixation and restricted visual field on vection-induced motion sickness. Aviat Space Environ Med. 61(8): 712-715.

Webb, NA and Griffin, MJ. (2002) Optokinetic stimuli: motion sickness, visual acuity, and eye movements. Aviat Space Environ Med, 73:351-358.

Yang, J.X., Guo, C.T., So, R.H.Y. and Cheung, R.T.F. (2011), Effects of Eye Fixation on Visually Induced Motion Sickness: Are they Caused by Changes in Retinal Slip Velocity? Proceedings of the Human Factors and Ergonomics Society Annual MeetingSeptember, vol. 55 no. 1 1220-1224.