Does your attention allocation affect how motion sick you can get?

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Abstract. Virtual reality (VR) applications desire maximum vection which is often accompanied by unwanted symptoms of Visually Induced Motion Sickness (VIMS). We report an experiment examining visual attention allocation in the central and peripheral visual field among VIMS susceptible and resistant participants, when exposed to large coherently rotating scene. Results supported our hypothesis that individual VIMS susceptibility is negatively associated with visual attention re-allocation during vection. Findings may enrich our understanding of VIMS and provide potential solutions to optimize vection without causing VIMS.

Keywords. VIMS; Vection; Visual Attention; Susceptibility.

1. Introduction

1.1 Vection and VIMS

Virtual reality (VR) technology has widespread applications in many areas such as medical, education and engineering (Burdea & Coiffet, 2003). However, the effectiveness and user experience of VR is often dependent on whether vivid illusions of self-motion are provoked in the simulated world. Vection, described as a sensation of self-motion without physical movement, is suggested to be a crucial element for improving VR (Riecke, 2011).

Behavioral studies on vection, dating back to 1870s (Mach, 1875), primarily focus on investigating its detailed psychophysical characteristics, including the time course, the intensity, the perceived velocities and how those properties were influenced by the stimuli features (Dichgans & Brandt, 1978; Palmisano, Allison, Schira, & Barry, 2015). Since most experimenters would prevent participants getting sick to ensure valid vection data, very limited studies have explored how vection is related to uncomfortable experiences (Keshavarz, Riecke, Hettinger, & Campos, 2015).

Meanwhile, conditions that are capable of inducing vection are often accompanied by visually induced motion sickness (VIMS), which is one of the major human factors concerns in VR environment (Ellis, 1991) that people wish to reduce or avoid. With extended exposure to a moving visual scene, the majority of stationary observers would experience varying severities of VIMS, typically reported as symptoms, including disorientation, oculomotor disturbances and gastrointestinal discomfort (Griffin, 2012; Stanney, Kingdon, & Kennedy, 2002). VIMS is usually associated with the generalised family of motion sickness (MS) except that physical motion is absent (Hettinger, Berbaum, Kennedy, Dunlap, & Nolan, 1990).

1.2 Sensory Conflict and Conflict Reduction Mechanisms

Among several theories that are dedicated to explaining the origins of VIMS/MS, 'sensory conflict theory' (Reason, 1978) is the most widely accepted (Keshavarz et al., 2015). The theory predicts that vection provoking stimuli should introduce sensory conflicts primarily between visual and vestibular systems which would then lead to mismatched neural activities resulting in VIMS.

However, 'sensory conflict theory' did not fully explain all the empirical observations that vection alone does not necessarily ensure the experience of VIMS (Hettinger et al., 1990; Riecke et al., 2004; So, Lo, & Ho, 2001), as other independent factors, especially individual differences, can have great influences on occurrence of VIMS (Diels & Howarth, 2011). To address this, the sensory conflict model was further developed by Brandt, which introduced a sensory conflict reduction mechanism between the visual and vestibular modalities (Brandt, Bartenstein, Janek, & Dieterich, 1998). According to Brandt, during vection, the vestibular system would be inhibited while the visual system should be more activated to resolve the conflicts. Thus, VIMS only happens when people fail to achieve this conflict reduction mechanism. However, although some neural imaging studies revealed stronger neural activation in the visual area during vection (Brandt et al., 2002; Della-Justina et al., 2014; Deutschländer et al., 2002), many other experiments actually reported deactivated activities in the visual system when accompanied with vection (Kleinschmidt et al., 2002; Stróżak et al., 2016; Thilo, Kleinschmidt, & Gresty, 2003).

These inconsistences may root in the fact that the human visual system is a rather complicated mega system, which is responsible for multiple tasks including self-motion perception. Therefore, the roles played by the visual and vestibular system should not be equal in Brandt's activation-inhibition mechanism, as for the visual system, only one of its sub-systems that is responsible for providing self-motion cues is primarily involved. All of the studies reported suppression or inhibited responses (both behavioral and neurological) when subjects were required to execute explicit visual tasks during vection (e.g. Thilo presented reversing checkerboard, Stróżak conducted oddball tasks). Conversely, experiments that discovered a stronger activated response generally did not require additional visual tasks except watching vection generating stimuli (Brandt et al., 1998; Thomas Brandt et al., 2002).

Moreover, most studies revealed suppression effects in the central visual field (Stróżak et al., 2016; Thilo et al., 2003). As peripheral rather than central visual field is primarily responsible for providing self-motion cues (Dichgans & Brandt, 1978), the suppression effect in the central visual field during vection actually suggests that visual processing emphasis might have been directed to self-motion perception, owning to one important property of the visual system—the limited visual attention resource.

1.3 Visual Attention Resource Allocation during Vection

According to the influential 'attention resource theory', the total resource for visual information processing is limited (Kahneman, 1973; Marois & Ivanoff, 2005). It is a general principle that the human visual system can shift processing emphasis by assigning more attention resource to one part of the visual area and withdraw resource from other parts (Cartwright-Finch & Lavie, 2007; Lavie, 2006). In general, attention acts as a torch that amplifies all responses within the attended area, while deactivating ignored areas (Schallmo, Grant, Burton, & Olman, 2016). Based on this, we inferred that during vection, the visual system might facilitate the conflict reduction mechanism by withdrawing attention resource from the central visual field and directing to the peripheral visual field. To test this hypothesis, we adopted the Go/No-Go visual target detection task, a common psychological paradigm for investigating visual attention (Liu, Healey, & Enns, 2003), to explore the attention resource re-allocation in the visual filed during vection and whether this re-allocation corresponds to VIMS susceptibilities. We measured task response time (RT) and accuracy (Acc) as indicators and examined the following hypotheses:

H1) behavioral performances (RT/Acc) on detecting targets are impaired in the central visual field during vection;

H2) Target detection performance is facilitated in the peripheral visual field during

vection;
H3) VIMS resistant subjects show stronger re-allocation effects.

2. Methods

2.1 Subject and Experiment Design

Nine subjects (5 male) aged from 22-26 (Mean (SD) = 23.25(1.49)) were recruited in a full factorial experiment with three 2-level within subject factors and 50 repetitions (Vection; Target Motion; Target Position). To test the effect of vection, two types of stimuli were generated: 700-750 randomly generated grey dots on a black background (size: 0.5~1.3° of FOV) either rotating coherently anticlockwise (angular velocity: 32°/s) to induce strong vection or with a randomised rotating center while keeping the same radius and angular velocity (Beer et al. 2002) as a control. To explore the visual attention allocation, there were two types of target (central versus peripheral). Central targets only appeared within the 2.1° of the central FOV, while peripheral targets would show up in the peripheral visual field ranging from 7.9° to 24.9° in FOV. Finally, two types of target (moving versus static) were used. For the static target, it would just appear and keep stationary on the screen, while the moving target would rotate anticlockwise with an angular velocity of 32°/s during the 500ms.

In sum, 400 trials (2 Vection Condition*2 Target Motion*2 Target Position*50 repetitions) were collected for each subject, while they were divided into 4 separate blocks, where each consisted of 100 trials (1 Vection Condition*1 Target Motion*2 Target Position*50 repetitions). Each block lasted around 2 min with a 2-3 min short rest between two blocks and a long break (5-8 min) after two blocks. Target position type was completely randomised within the block, while type of target motion and vection condition was assigned to each block randomly.

2.2 Procedure

During the whole experiment, subjects were instructed to fix their eyes on the central grey circle (radius: 2.5° of FOV). They were trained to press the button with their right hand to indicate their perception state (experiencing vection or not), while using the left hand to execute the target detection task, which required pressing a button when a target was detected (red dot) that randomly appeared, but withhold the response when a distraction (green dot) appeared.

For each trial, the target/ distraction (randomized with ratio: 4/1) was presented for 500ms, and followed by a period of trial interval randomly ranged 1~1.5s before next target/distraction appeared. Subjects were trained to report vection intensity after each block based on a 5-point vection magnitude scale revised from previous studies (1= no vection; 5=saturated vection (Webb & Griffin, 2003)). All subjects received training of the button press task across 100 trials as well as sufficient training on vection (self-motion perception) judgement before the experiment. VIMS susceptibility data of all subjects were collected after the whole experiment (see Figure 3 for distribution of MSSQ score of subjects) using the Motion Sickness Susceptibility Questionnaire (MSSQ) Short-form (Golding, 1998).

2.3 Apparatus

During the experiment, subjects sat in front of a 46 inch LCD TV with a view distance of 48cm (Screen size: 102.1cm X 57.5cm; FOV: 93.5°X 61.8°) and a chin-rest to control head and body movement. To reduce environmental influences, the ceiling light was switched-off and ear-plugs were used, while the TV and head of subject(s) was enclosed by a black curtain. All control and display programs were coded with Psychtoolbox-3, Matlab.

3. Results

3.1 Vection Report

All subjects reported explicit vection (Mean=2.33, SD=0.90) in the coherently rotating (Vection) condition, while only 4 subjects reported very weak vection feelings for a short time period in the rotating center randomised (Control) condition. Since the stimuli exposure time was very short (<3min) for each block, no subjects reported any unpleasant feelings or nausea.

3.2 Data pre-processing

For following data analysis, only trials indicated by subjects as during the vection perception state were kept as valid trials for the vection condition, while only trials indicated by subjects as no vection (stationary perception state) were kept as valid trials for the control condition. The total percentage of valid trials across all blocks was 88.92%, with no significant differences between blocks. Moreover, trials before and after the right hand response (subject indicated perception state change) were excluded to eliminate the interference of dual task. Trials with a response time (RT) less than 200ms (which is impossible for a human, indicating a false report) were excluded (total percentage <1%).

The final mean RT and Accuracy (calculated by amount of accurate response divided by amount of valid trials) were calculated among valid trails for each condition.

3.3 Main Effect and Interaction Effect

All of the main effects as well as interaction effects were significant ($p<0.01$). In general, subjects demonstrated higher response accuracy in central targets compared to peripheral targets as well as higher accuracy in moving targets than static targets. Vection effects were complicated because of very strong interactions, which will be illustrated in detail later.

For RT, the main effect of target position was significant ($F(1,8)=163.925$, $p<0.001$), where subjects reacted faster for central targets than peripheral targets as expected. The interaction effect between target position and vection was significant ($F(1,8)=9.798$, $p=0.014$), which supports **H1/H2**. Further simple-interaction effect tests revealed that the interaction (position X vection) was only significant under the static target condition for both RT and Acc ($p<0.05$; see **Figure 1** for an illustration). Moreover, target motion and vection also had a significant interaction effect ($F(1,8)=18.291$, $p=0.003$). The main effect of vection has a trend ($p=0.09$) but is not significant, possibly due to the influence of the significant interaction effect. Hence, to better interpret the findings, implications of results regarding the central and peripheral visual field will be discussed separately in details.

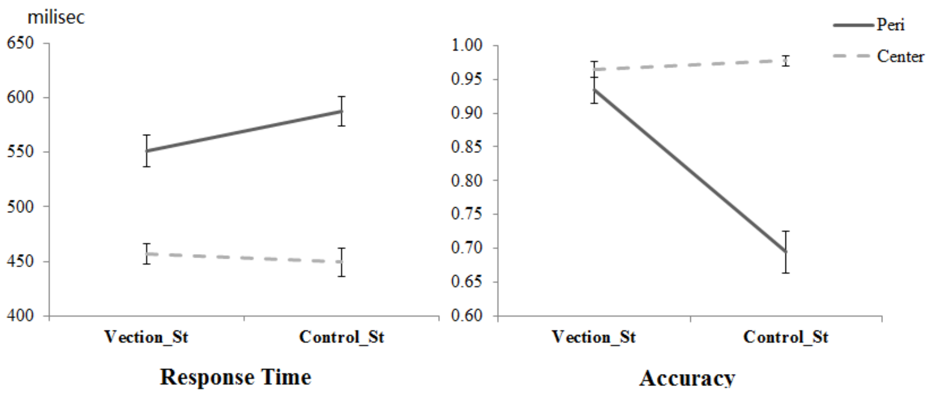

Figure 1 RT and Acc under static targets conditions

3.4 Central Field Effect

For RT, vection showed a significant simple main effect in the central target condition (F(1,8)=9.393, p=0.015), where subjects showed slower RT in the vection condition comared to the control condition. Moreover, the simple interaction effect of target motion and vection was marginally significant (F(1,8)=7.271, p=0.062). It is worth mentioning that, the simple vection effect was only significant under the moving target condition (F(1,8)= 10.117, p=0.013), while for the static target, there was a trend but no significance (see **Figure 2.a**).

For Accuracy, no significant effect was found, which indicates the effect in RT was not influenced by a RT-Accuracy trade off.

In summary, behavioral performances were impaired in the detection task during vection in the central visual field, where especially less sensitivity to a moving target was revealed, which supported **H1**.

3.5 Peripheral Field Effect

For RT, the simple interaction effect between target motion and vection in the peripheral visual field was significant (F(1,8)= 14.209, p=0.005). Due to the strong interaction effect, no simple main effect was found. Subjects demonstrated slower RT for the moving target during vection, while showed faster RT for the moving target without vection (see **Figure 2.b**).

For Accuracy, both the simple main effect of target motion and vection, along with the simple interaction effect between target motion and vection was significant (all p<0.001). It is worth to point out that, the simple-simple effect analysis found faster RT under static target condition (F(1,8)=46.185***, p<0.001), while no significant difference was found for the moving condition, which means the behavioral performance of RT and Accuracy were consistent and the effects were not due to a RT-Acc trade off (see **Figure 2.c**).

In summary, in the peripheral visual field, improved accuracy performance was found during vection (pooling trials for all type of targets together), which supported **H2**. Moreover, during the vection condition, the detection response time for the static target was shorter than for the moving target, while opposite results were found under control condition (see **Figure 2.b**).

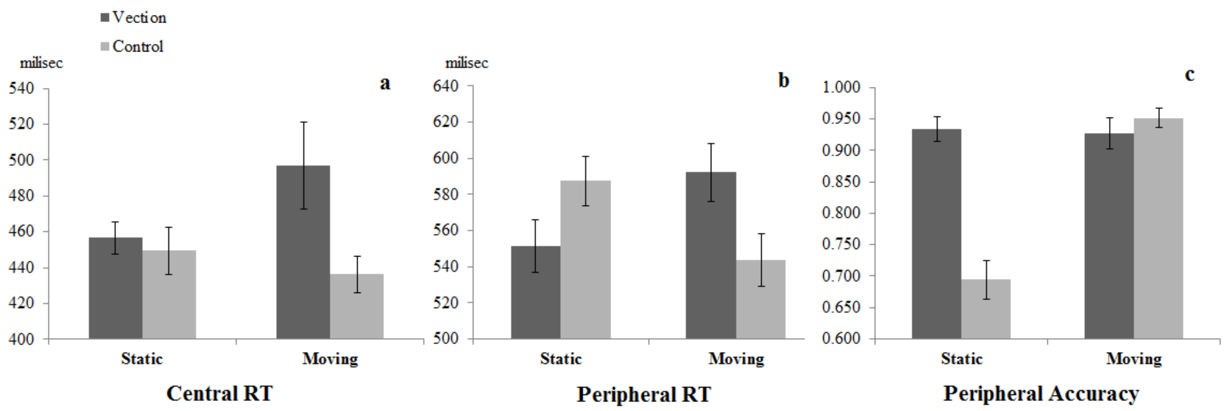

Figure 2 Separate Vection effects on Central and Peripheral Field

3.6 Correlation between Effects and MSSQ scores

Since a significant vection X position interaction effect was only found under the static target condition, a Pearson Correlation between MSSQ-short scores (including Total, Child and Adult-scale) and the magnitude of vection effects on the static target was examined respectively (see **Table 1** for Coefficient and p-value, see **Figure 3** for scatter plots). The magnitude of central/peripheral effects were indicated using the difference of response time (with vection condition minus control condition) and total effect was combined using central effect minus peripheral effect (as the two effects should move in opposite directions as we hypothesised).

Table 1 Correlation between Vection effects and MSSQ scores

MSSQ Scales\Effects	Central Effect	Peripheral Effect	Total Effect
Total	-0.540(0.067)	0.378(0.158)	-0.630(0.034)
Adult	-0.386(0.152)	0.610(0.041)	-0.792(0.005)
Child	-0.618(0.038)	-	-0.261(0.249)

In summary, MSSQ scores can significantly predict the vection effects on RT under the static target condition for both the central and peripheral field, where VIMS resistant subjects showed stronger effects than their susceptible contemporaries. These findings supported **H3**.

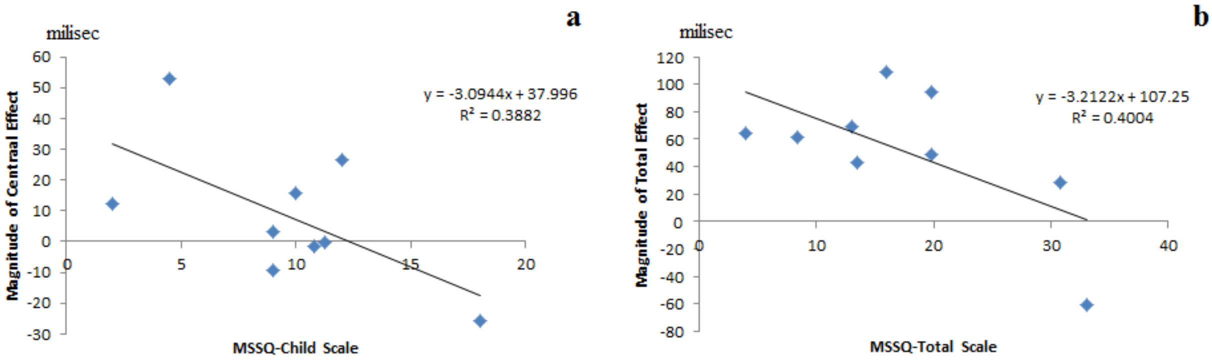

Figure 3 Scatter plots of Vection effects and MSSQ scores

4. Discussion and Conclusion

This study used a target detection task to examine the visual attention performance during vection on both the central and peripheral visual field. As the performance of visual tasks can reflect attention resource allocation (Liu et al., 2003), our findings of improved performance in the peripheral and impaired performance in the central visual field during vection supported the hypothesis that more attentional resource could be withdrawn from the central to the peripheral area during conflicting visual input. This finding was also consistent with several former functional brain studies (Kleinschmidt et al., 2002; Stróżak et al., 2016; Thilo et al., 2003), which found deactivated neural activity of the central visual field when subjects reported vection.

To our best knowledge, this experiment is among the first attempts to explore and compare the influence of vection on the central and peripheral field together. More importantly, the promising conflict reduction hypothesis was further examined by testing the correlation between the attention allocation effects and VIMS susceptibility which may contribute to better understanding of the relationship between vection and VIMS. Moreover, if allocating more attentional resource to the peripheral visual field helps to prevent VIMS during vection as the findings suggested, practical strategies can be applied in VR environments to reduce undesired sickness experiences. More data should be collected to consolidate current findings. As only one type of speed was explored in the moving target condition, further explorations are needed to clarify the difference between static and moving targets.

Acknowledgement
This study is partially funded by the Hong Kong Grants Council via 618812 and 16200915.

References

Brandt, T., Bartenstein, P., Janek, A., & Dieterich, M. (1998). Reciprocal inhibitory visual-vestibular interaction. Visual motion stimulation deactivates the parieto-insular vestibular cortex. *Brain : A Journal of Neurology*, *121*, 1749–58.

Brandt, T., Glasauer, S., Stephan, T., Bense, S., Yousry, T. A., Deutschlander, A., & Dieterich, M. (2002). Visual-vestibular and visuovisual cortical interaction: new insights from fMRI and pet. *Annals of the New York Academy of Sciences*, *956*, 230–41.

Burdea, G., & Coiffet, P. (2003). *Virtual Reality Technology, Second Edition with CD-ROM*. Wiley-IEEE Press.

Cartwright-Finch, U., & Lavie, N. (2007). The role of perceptual load in inattentional blindness. *Cognition*, *102*(3), 321–340.

Della-Justina, H. M., Gamba, H. R., Lukasova, K., Nucci-da-Silva, M. P., Winkler, A. M., & Amaro, E. (2014). Interaction of brain areas of visual and vestibular simultaneous activity with fMRI. *Experimental Brain Research*. pp.237-252.

Deutschländer, A., Bense, S., Stephan, T., Schwaiger, M., Brandt, T., & Dieterich, M. (2002). Sensory system interactions during simultaneous vestibular and visual stimulation in PET. *Human Brain Mapping*, *16*(2), 92–103.

Dichgans, J., & Brandt, T. (1978). Visual-vestibular interactions : effects of self-motion perception and postural control. *Handbook of Sensory Physiology*, *8*, 755–804.

Diels, C., & Howarth, P. A. (2011). Visually induced motion sickness: Single- versus dual-axis motion. *Displays*, *32*(4), 175–180.

Ellis, S. R. (1991). Nature and origins of virtual environments: a bibliographical essay. *Computing Systems in Engineering*, *2*(4), 321–347.

Golding, J. F. (1998). Motion sickness susceptibility questionnaire revised and its relationship to other forms of sickness. *Brain Research Bulletin*, *47*(5), 507–16.

Griffin, M. J. (2012). *Handbook of Human Vibration*. Academic Press.

Hettinger, L. J., Berbaum, K. S., Kennedy, R. S., Dunlap, W. P., & Nolan, M. D. (1990). Vection and simulator sickness. *Military Psychology : The Official Journal of the Division of Military Psychology, American Psychological Association*, *2*(3), 171–81.

Kahneman, D. (1973). *Attention and effort. Englewood Cliffs, NJ*. Prentice-Hall.

Keshavarz, B., Riecke, B. E., Hettinger, L. J., & Campos, J. L. (2015). Vection and visually induced motion sickness: how are they related? *Frontiers in Psychology*, *6*, 472.

Kleinschmidt, A., Thilo, K. V, Büchel, C., Gresty, M. A., Bronstein, A. M., & Frackowiak, R. S. J. (2002). Neural correlates of visual-motion perception as object- or self-motion. *NeuroImage*, *16*(4), 873–82.

Lavie, N. (2006). The role of perceptual load in visual awareness. *Brain Research*,1080,91–100.

Liu, G., Healey, C. G., & Enns, J. T. (2003). Target detection and localization in visual search: a dual systems perspective. *Perception & Psychophysics*, *65*(5), 678–94.

Mach, E. (1875). *Grundlinien der Lehre von den Bewegungsempfindungen*. W. Engelmann.

Marois, R., & Ivanoff, J. (2005). Capacity limits of information processing in the brain. *Trends in Cognitive Sciences*, pp.296-305.

Palmisano, S., Allison, R. S., Schira, M. M., & Barry, R. J. (2015). Future challenges for vection research: definitions, functional significance, measures, and neural bases. *Frontiers in Psychology*, *6*, 193.

Reason, J. T. (1978). Motion sickness adaptation: a neural mismatch model. *Journal of the Royal Society of Medicine*, *71*(11), 819–29.

Riecke, B. E. (2011). *Virtual Reality*. (J.-J. Kim, Ed.). InTech, pp.149-176.

Riecke, B. E., Schulte-pelkum, J., Avraamides, M. N., Bülthoff, H. H., Planck, M., & Cybernetics, B. (2004). Enhancing the Visually Induced Self-Motion Illusion (Vection) under Natural Viewing Conditions in Virtual Reality. *Proceedings of 7th, Annual*

International Workshop Presence, Valencia, Spain, 125–132.
Schallmo, M.-P., Grant, A. N., Burton, P. C., & Olman, C. A. (2016). The effects of orientation and attention during surround suppression of small image features: A 7 Tesla fMRI study. *Journal of Vision*, *16*(10), 19.
So, R. H., Lo, W. T., & Ho, A. T. (2001). Effects of navigation speed on motion sickness caused by an immersive virtual environment. *Human Factors*, *43*(3), 452–461.
Stanney, K. M., Kingdon, K. S., & Kennedy, R. S. (2002). Dropouts and Aftereffects: Examining General Accessibility to Virtual Environment Technology. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *46*(26), 2114–2118.
Stróżak, P., Francuz, P., Augustynowicz, P., Ratomska, M., Fudali-Czyż, A., & Bałaj, B. (2016). ERPs in an oddball task under vection-inducing visual stimulation. *Experimental Brain Research*, 234, 1–10.
Thilo, K. V, Kleinschmidt, A., & Gresty, M. A. (2003). Perception of self-motion from peripheral optokinetic stimulation suppresses visual evoked responses to central stimuli. *Journal of Neurophysiology*, *90*(2), 723–30.
Webb, N. A., & Griffin, M. J. (2003). Eye movement, vection, and motion sickness with foveal and peripheral vision. *Aviation, Space, and Environmental Medicine*, *74*(6), 622–5.