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Eye movement, vection and motion sickness with foveal and peripheral vision

by

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Abstract

Background: Both motion sickness and the illusion of self-motion (i.e. vection) can be induced by moving visual scenes. The results of a previous study imply that motion sickness is primarily dependent on visual motion in foveal vision while vection is primarily dependent on motion in peripheral vision. **Hypotheses:** It was hypothesised that similar motion sickness would be produced when tracking a single moving dot and a full screen of moving dots but that vection would be greater when tracking multiple moving dots. **Method:** Sixteen subjects viewed moving images presented on a virtual reality head-mounted display. In one condition a single dot moved from left to right at 27°/second over a distance of 18° before returning instantly to its starting point. This motion was repeated continuously. In a second condition, five horizontal rows of dots, each 18° apart, moved continuously across the screen at 27°/second; subjects were instructed to track each dot in the central row as it passed. **Results:** In both conditions, there were nystagmic eye movements with an approximate amplitude of 18° at 27°/second. Vection differed significantly between the two conditions, with more vection in the condition with five rows of dots. Subjects experienced motion sickness symptoms with both the single moving dot and the five rows of dots, with no significant difference in sickness between the two conditions. Subject ratings of motion sickness and vection were not correlated with each other in either of the two conditions. **Conclusions:** Motion sickness and vection can vary independently. Vection appears to be influenced by peripheral vision, as there was an increase in vection with full-field stimulation. Motion sickness induced by moving visual scenes may be influenced by foveal visual stimulation or by eye movements, as these were the same in both conditions.

1 INTRODUCTION

The illusion of self-motion can be experienced with some motion simulators, virtual reality displays, cinema films and in some real life situations. Studies measuring motion sickness and vection have not shown there to be a correlation between the two phenomena. Despite this, the phrase 'vection-induced motion sickness' is frequently used in the literature (e.g. Reid [10], Hu et al. [8]). Vection has also been investigated as a substitute for studying motion sickness, with the conclusion that the condition which produces the greatest vection will also produce the greatest motion sickness.

Peripheral vision is a dominant influence on vection experienced during exposure to visual stimulation in an optokinetic drum. Brandt et al. [1] showed that experiences of vection in an optokinetic drum were reduced by blocking part of peripheral vision with blinkers. It was also found that, when presented with a central optokinetic stimulus moving in the opposite direction to the peripheral stimulus, subjects tracked the central stimulus (optokinetic nystagmus) but experienced vection in the direction expected from the peripheral stimulus. Several experiments have measured vection and motion sickness and found that the condition which produces the greatest vection also produces the greatest motion sickness. However, evidence of a causal relation between vection and motion sickness has not been shown.

Visually-induced motion sickness is lowered during fixation: subjects focusing on a stationary cross in front of an optokinetic stimulus suppressed optokinetic nystagmus and reported less motion sickness (Webb and Griffin [12]). Vection was not significantly affected by the fixation, indicating that vection is mainly dependent on peripheral vision and independent of eye movements. It has been proposed that nystagmus may be responsible for motion sickness: Ebenholtz et al. (3) suggested that eye movements might elicit afferent signals that stimulate the vagus nerve which, due to its proximity to the vestibular nuclei, may result in stimulation of the vestibular system. Since labyrinthine defective subjects experience vection but do not

appear to experience symptoms of motion sickness when exposed to optokinetic stimuli (Cheung *et al* [2]), Ebenholtz *et al.* (3) suggested that as a functioning vestibular system is necessary for motion sickness, eye movements may be responsible for a vestibular input which causes motion sickness via an unknown mechanism.

Whilst vection may be influenced mainly by peripheral vision, during exposure to optokinetic stimuli, optokinetic nystagmus appears to be dominated by foveal vision. Van Die *et al.* (11) studied eye movements in response to optokinetic stimuli presented to the central and peripheral retina, with stimulation of the central or peripheral retina achieved by masking the unwanted part of the visual scene. The masking systems tracked the horizontal eye movements and thus prevented stationary edges from suppressing eye movements (i.e. there were no fixation points). Scotopic viewing conditions were used (i.e. at a low level of illumination) so that the central retina would not be stimulated. Three patients with a unilateral central retinal scotoma (giving very poor central vision in one eye) were also studied. In each of the conditions it was found that the velocity of the slow phase of nystagmus was lower when the central retina was not stimulated: this was the case whether masks were used, scotopic versus photopic illumination, or subjects with central retinal scotoma in one eye viewed the stimulus with the affected or the normal eye.

The experiment reported here investigated whether vection and motion sickness were correlated within individuals and whether motion sickness or vection could be produced by a single moving dot tracked visually by subjects. The experiment also investigated whether motion sickness or vection differed with a full field of moving dots (which stimulated both foveal and peripheral vision) compared with a single moving dot (which only stimulated foveal vision). The two conditions were designed to create identical foveal stimulation which, due to the dominance of the fovea in the generation of nystagmus, would produce identical eye movements. The difference between the two conditions was that peripheral visual stimulation was much greater in the multiple dot condition.

It was hypothesised that vection would be greater with the multiple dot condition because of the greater stimulation of peripheral vision. It was hypothesised that motion sickness would be influenced by either foveal vision or by eye movements, and would therefore not vary between the two conditions that were expected to result in identical eye movements and identical foveal stimulation. Additionally, it was hypothesised that within subjects the motion sickness and vection would not be correlated.

The experiment has relevance to the design of virtual reality displays and motion simulators. If vection influences motion sickness, the sickness might be reduced by minimising the peripheral vision displayed to subjects. If, however, foveal stimulation is a primary influence on motion sickness other means of reducing sickness may be needed.

2 APPARATUS AND METHODS

The two conditions, with a single dot and a multiple dot, were displayed on a head-mounted display (Virtual Research VR4) having a visual field approximately 48° horizontally by 36° vertically. The focal point of the display was at approximately 1 metre. The same image sequence was presented to both eyes simultaneously. The animation was programmed using Kinetix' 3D Studio Max 1.2 rendered as a Microsoft Video for Windows AVI file presented at 60 frames per second. During the experiment, the graphics card was set to 60 Hz refresh rate so that each video frame was presented once.

Eye movements were recorded by the means of electro-oculography. Three disposable electrodes were attached to each subject (just above the bridge of the nose and the outer canthis of each eye). The electrode signals were amplified by a 'Hortmann electro-nystagmograph' and converted to digital form with an *HVLab* data acquisition computer at a rate of 30 samples per second via a low pass filter at 10Hz. Each signal was viewed and analysed using the *HVLab* software. The accuracy of electro-oculography recordings was in the region of 0.5 to 1.0 degree of visual angle (Hallett [7]). Eye movements were calibrated

by asking subjects to look at 3 crosses aligned horizontally on a wall with 15° angular separations.

Visual acuity (without correction) was measured using a Keystone visual skills test conducted at a near point (2.5 dioptres, 0.4 m) and at a far point (0.25 dioptres, 4m). Visual acuity could be measured from 20:200 (low) to 20:15 (high). All subjects had normal near visual acuity (20:20 or better) with the exception of one subject who had 20:30 vision.

Sixteen male subjects, aged 20 to 25 years, participated in the experiment. Subjects were not selected on the basis of motion sickness susceptibility. Subjects viewed two conditions on the Virtual Research VR4 head-mounted display: (i) a single dot which moved from left to right over a distance of 18° at a rate of 27°/second before jumping back to its starting position and repeating in an infinite loop (see Figure 1a); (ii) five horizontal rows of dots, with each dot 18° apart, moving continuously from left to right at a rate of 27°/second (see Figure 1b). Each subject experienced both conditions. Eight subjects commenced with the single dot and eight commenced with the multiple dot display. The two exposures were performed at the same time of day, but with at least two weeks between the two exposures so as to reduce any habituation effects.

FIGURE 1 ABOUT HERE

During each exposure, at one-minute intervals for a total of 30 minutes, subjects rated their motion sickness on a 7-point scale (0: No symptoms; 1: Any symptoms, however slight; 2: Mild symptoms, e.g. stomach awareness but no nausea; 3: Mild nausea; 4: Mild to moderate nausea; 5: Moderate nausea but can continue; 6: Moderate nausea and want to stop. The rating scale is adapted from Golding and Kerguelen [6]). At the same time, the subjects rated their vection on a percentage scale (Table 1). Following each exposure, subjects completed a symptom questionnaire, based on that used by Kennedy and Fowlkes (9).

TABLE 1 ABOUT HERE

With the single dot, subjects were asked to track the dot continuously as it moved from left to right and jumped back to its starting position. With the multiple dots, subjects were asked to track each dot in the middle row as it passed. In this way the foveal stimulus and eye movements were expected to be identical in the two conditions: a single dot moving from left to right at 27°/second for approximately 18° followed by return to the next dot.

Subjects gave their informed consent to participate in the experiment that was approved by the Human Experimentation Safety and Ethics Committee of the Institute of Sound and Vibration Research.

3 ANALYSIS

Motion sickness ratings were summed over the 30-minute exposure period to give an 'accumulated illness rating' for each subject (Griffin and Howarth [5]). If a subject terminated the session (i.e. reached a rating of 6 on the motion sickness scale), a rating of 6 was assigned for the remaining period. Vection scores were summed and divided by the total number of minutes of exposure to give an average vection rating.

The illness ratings and the vection ratings were compared across conditions using Wilcoxon matched-pairs signed ranks. Correlations between illness ratings and vection ratings within conditions were investigated using Spearman's rank correlation.

4 RESULTS

4.1 Eye movements

The electro-oculographic data were inspected by eye for indications that the eye movements were similar in each of the conditions. The eye movements were nystagmic, with a smooth pursuit of approximately 18° followed by a rapid return saccade, with a frequency of 1.5 Hz, in both conditions. Inspection revealed that the eye movement of every subject was continuous throughout each exposure condition, indicating that tracking of the dots for long

periods was possible. Time-frequency analysis revealed that the power in each set of eye movements was primarily at about 1.5 Hz in both conditions. It was therefore concluded that the experimental design resulted in eye movements that were similar in both conditions. The foveal stimulation (of a single moving dot) was therefore very similar in both conditions, whilst the peripheral stimulus was either nothing (single dot) or 14 continuously moving dots (multiple dots).

4.2 Motion sickness

The mean accumulated illness ratings were 19.9 for the single dot and 22.8 for the multiple dots. There was no significant difference between the illness ratings in the two conditions (Wilcoxon, p=0.706). The number of subjects to reach each point on the motion sickness scale are shown in Table 2. The post exposure symptoms questionnaire also showed no difference between the two conditions (Wilcoxon, p>0.460). There was a significant correlation between the accumulated illness ratings in the two conditions (ρ=0.516, p<0.05). There was no correlation between vection and motion sickness ratings with the single dot condition (ρ=0.191, p>0.494) or with the multiple dot condition (ρ=0.184, p>0.479). The mean illness ratings during the 30-minute exposure are shown in Figure 2.

FIGURE 2 ABOUT HERE

TABLE 2 ABOUT HERE TOO.

4.3 Vection

There was a significant difference between the mean vection scores in the two conditions: 12.6% with the single dot and 27.4% with the multiple dots (p<0.05, Wilcoxon). Between conditions, the vection scores were significantly correlated (ρ=0.551, p<0.05), indicating that subjects reporting more vection in one condition were likely to report more vection in the other condition, even though there was appreciably greater vection in the multiple dot condition. The vection reported with the single dot condition might have been due to the way

in which the single dot was displayed. There were two frames each second (1/30th of one second) where the two dots shown in Figure 2 were visible simultaneously. This will have resulted in some stimulation of the peripheral retina.

5 DISCUSSION

Vection

In this experiment, vection was significantly increased with greater peripheral visual stimulation. Eye movements were similar in the two conditions with single and multiple dots. This is consistent with vection not being solely determined by eye movements. The results from a previous study (Webb and Griffin [12]) showed that vection did not change significantly with or without visual fixation (where nystagmus was suppressed with fixation), which also indicated that vection is not solely determined by eye movements.

Motion Sickness

Motion sickness did not differ significantly between the two conditions. The difference in vection between the two conditions, and the absence of correlations between vection and motion sickness within both conditions, suggests that vection was not a primary cause of motion sickness. Eye movements and foveal stimulation were the same in the two conditions, suggesting that either eye movements or the movement of images on the fovea are the cause of motion sickness in the conditions of this experiment.

Visual acuity was a factor influencing motion sickness in a previous experiment (Webb and Griffin [12]). This was not studied in the present experiment due to the low variability in subject near point visual acuity.

The overall motion sickness scores in this experiment were low, with a mean illness rating at 30 minutes of around 1.2 in both conditions. However, this is higher than the mean illness rating at 30 minutes of 0.4 for a control condition, with no motion, recorded in a previous

experiment (Griffin and Mills [6]). This would appear to confirm that subjects were experiencing symptoms of motion sickness as a result of the visual stimulation.

6 CONCLUSIONS

Reducing peripheral visual stimulation may reduce vection but the results of the present study and the results of a previous study with visual fixation (Webb and Griffin, [12]) suggest it may not reduce motion sickness. Since motion sickness and vection can vary independently it cannot be assumed that reductions in vection will always be accompanied by reductions in motion sickness. This has implications for the design of simulators and virtual reality displays.

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Table 1. Vection scale. Subjects reported a percentage score (between 0 and 100%) each minute to indicate their perception of self-motion.

Perception of motion (vection)	You report:
You feel like you are stationary and it is the dot(s) which appear to be moving only.	0%
You feel like you are moving a bit, but the dot(s) are moving more	1 - 49%
You feel like you are moving at the same speed as the dot(s)	50%
You feel like you are moving a lot and the dot(s) are moving a bit	51 - 99%
You feel like you are moving and the dot(s) appear stationary	100%

Table 2. Number of subjects to reach each illness rating in the two conditions.

Illness Rating	**Multiple dot condition**	**Single dot condition**
0: No symptoms	16	16
1: Any symptom, however slight	13	12
2: Mild symptoms e.g. stomach awareness, but no nausea	5	7
3: Mild nausea	2	2
4: Mild to moderate nausea	2	1
5: Moderate nausea, but can continue	1	1
6: Moderate nausea, want to stop	1	1

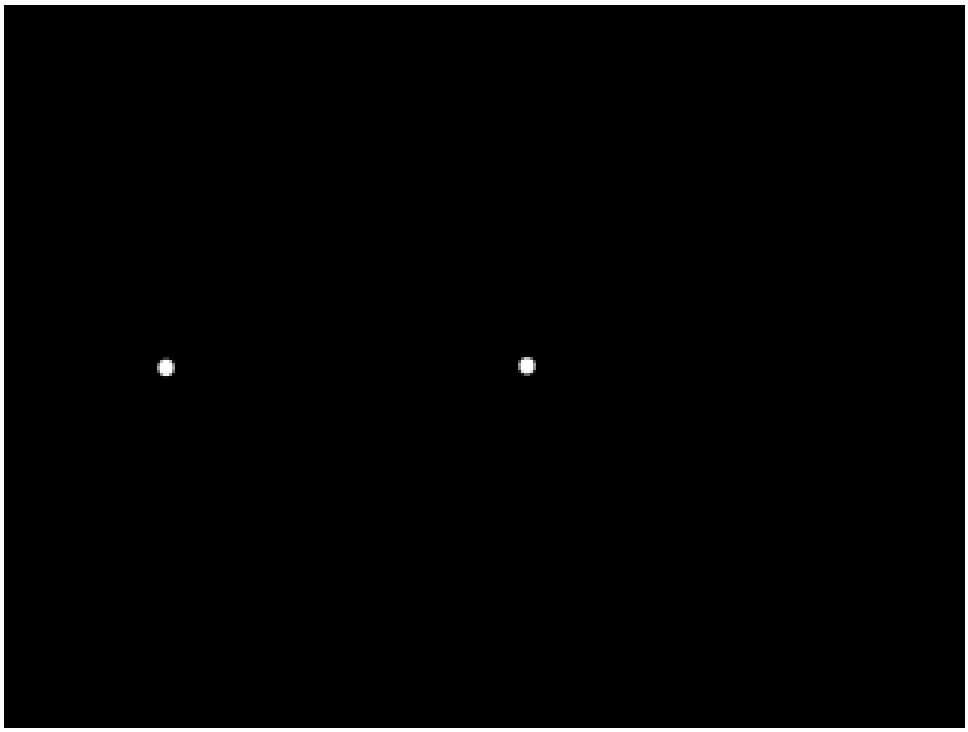

Figure 1a. The start and end point for the single dot.

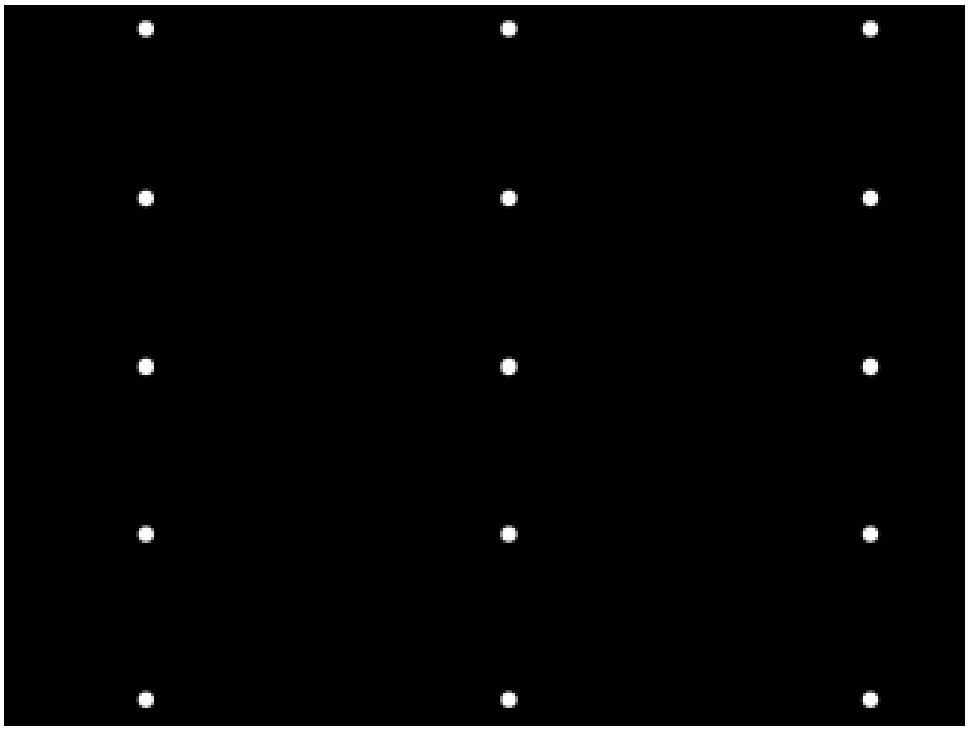

Figure 1b. The full field of multiple dots.

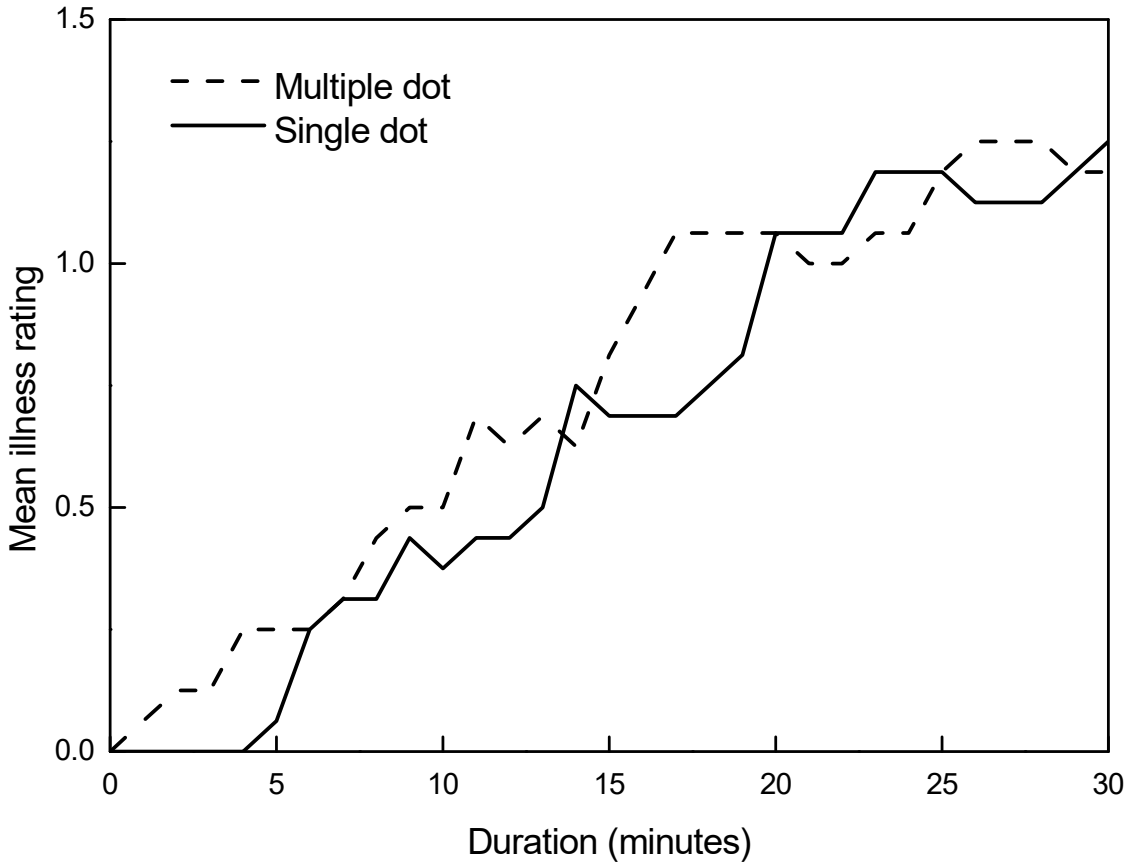

Figure 2. Mean illness ratings for the single dot and multiple dot conditions over the 30-minute exposure.