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# Optokinetic Stimuli: Motion Sickness, Visual Acuity and Eye Movements

by

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Running header: **Motion sickness caused by optokinetic stimulation**

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## Abstract

***Background:*** It is commonly assumed that motion sickness caused by moving visual scenes arises from the illusion of self-motion (i.e. vection). ***Hypotheses:*** Both studies reported here investigated whether sickness and vection were correlated. The first study compared sickness and vection created by real and virtual visual displays. The second study investigated whether visual fixation, to suppress eye movements, affected motion sickness or vection. ***Method:*** In the first experiment, subjects viewed an optokinetic drum and a virtual simulation of the optokinetic drum. The second experiment investigated two conditions on a virtual display: (i) moving black and white stripes and (ii) moving black and white stripes with a stationary cross on which subjects fixated to reduce eye movements. ***Results:*** In the first study, ratings of motion sickness were correlated between the conditions (real and the virtual drum), as were ratings of vection. With both conditions, subjects with poor visual acuity experienced greater sickness. There was no correlation between ratings of vection and ratings of sickness in either condition. In the second study, fixation reduced motion sickness but had no affect on vection. Motion sickness was correlated with visual acuity without fixation, but not with fixation. Again, there was no correlation between vection and motion sickness. ***Conclusions:*** Vection is not the primary cause of sickness with optokinetic stimuli. Vection appears to be influenced by peripheral vision whereas motion sickness is influenced by central vision. When the eyes are free to track moving stimuli, there is an association between visual acuity and motion sickness. Virtual displays can create vection and may be used to investigate visually-induced motion sickness.

Keywords: motion sickness, vection, optokinetic, nystagmus, visual acuity, fixation, virtual reality

# 1 Introduction

Motion sickness caused by moving visual scenes can be studied using 'optokinetic drums' - usually black and white striped cylinders rotating about a vertical axis around a seated subject (1). This stimulus also produces the illusion of self-rotation, known as circular-vection. The motion sickness and vection experienced by subjects depend on the characteristics of the moving scene within such a drum. It has been suggested that visual displays producing the greatest vection also cause the highest incidence of sickness (8).

By means of masks inside a drum, Brandt *et al.* (1) presented a moving stimulus to either the peripheral or the central visual field. Using a mirror, giving a central visual field with stripes moving in the opposite direction to those in the periphery, eye movements were found to track the direction of the central stripes while vection occurred in the direction determined by the peripheral field. This suggests that motion in the periphery is the primary cause of circular-vection.

Asking subjects to focus on a stationary cross within an optokinetic drum has been reported to inhibit nystagmus, reduce motion sickness and slightly reduce vection (11). Observing that anaesthetising the muscles behind the eye reduced sickness after surgery, Ebenholtz *et al.* (3) proposed that nystagmus may be responsible for motion sickness. They 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. A study by Cheung *et al.* (2) showed that labyrinthine defective subjects did not experience symptoms of motion sickness when exposed to optokinetic stimuli, without making head movements. They did experience vection. Johnson *et al.* (9) showed that labyrinthine defective subjects could experience motion sickness when making head movements (pseudo-coriolis effect) and that there was no significant difference in motion sickness or vection experienced between normal and labyrinthine defectives in response to pseudo-Coriolis stimuli in an optokinetic drum. Ebenholtz *et al.* (3) suggested that a functioning vestibular system is necessary for motion

sickness and that the input from eye movements may be a likely cause of the vestibular stimulation.

Several studies have investigated the contributions of central (foveal) and peripheral vision to optokinetic nystagmus (7,12). Van Die *et al.* (12) used masks to block either the foveal or peripheral vision and also compared scotopic viewing conditions (low level light to stimulate only the peripheral receptors) to photopic viewing conditions. It was found that the velocity of the slow phase of nystagmus was significantly slower when there was no foveal stimulation, i.e. when the fovea was blocked or was not stimulated (in the scotopic light condition). This indicates that the fovea is important in maintaining the correct speed of tracking in response to optokinetic motion.

The first experiment reported here investigated whether vection and motion sickness were related and whether circular vection and motion sickness could be generated using the restricted field of view on a 'virtual reality' head-mounted display. Specifically, the experiment investigated whether the motion sickness ratings of subjects within an optokinetic drum were correlated with those given when they observed the same field of view in a 'virtual drum'. Virtual reality allows flexibility in varying the visual display and has the potential to replace traditional optokinetic drums, mirror systems and other optical display devices (e.g. film projectors) that have been used to investigate motion sickness and vection.

In the second experiment the head-mounted visual display was used in two conditions: (i) black and white stripes moving as in the first experiment, and (ii) with a stationary fixation cross positioned in front of the moving stripes. Motion sickness, vection and eye movements were monitored to investigate whether fixation had similar effects on both motion sickness and vection. If vection and motion sickness vary independently, mechanisms independent of vection will be required to explain motion sickness caused by moving visual scenes.

The area of research is relevant to the prediction and reduction of motion sickness in virtual reality displays and the performance of pilots who will increasingly rely on information presented to them via head-mounted displays and other cockpit visual information systems.

# 2 Experiment 1: Comparison of vection and motion sickness in a real and virtual optokinetic drum

The first experiment was designed to compare reports of motion sickness produced by a real optokinetic drum with those produced by a virtual simulation of the drum using a head-mounted binocular display. It was predicted that there would be large inter-subject differences in motion sickness but that, for each individual subject, the two environments would produce similar sickness. Consequently, across the group of subjects, it was hypothesised that there would be a correlation between sickness ratings obtained in the two conditions. It was also hypothesised that, within conditions, ratings of motion sickness would be correlated with ratings of vection.

## *2.1 Apparatus*

In part of the experiment, subjects sat inside an optokinetic drum (height 1.2 metres, diameter 1.0 metre), painted internally with alternate black and white stripes (75mm wide, subtending 8º at the subjects' eyes), illuminated by a 5w halogen bulb, rotating at 5 revolutions per minute (30º per second). The luminance of the black stripes was 1.44 candelas/$m^2$. The luminance of the white stripes was 31.28 candelas/$m^2$. A strap connected to the backrest of a chair restrained the head of each seated subject. Subjects wore spectacles designed to restrict their field of view to 48º horizontally and 36º vertically.

In the other part of the experiment, an animation of the optokinetic drum was presented 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 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. Each black and each white stripe subtended approximately 8° at the eye and moved across the screen at 30°/second, so as to

give a similar visual experience to being in the real drum rotating at 5 r.p.m. Whilst watching the animation, subjects sat inside the real drum (which was rotating) so that the environment (i.e. sound, temperature and enclosed feeling) was similar in both conditions. The same system was used to restrain the head in both conditions.

### *2.2 Method*

Sixteen male subjects, aged 20 to 28 years (mean 22.9 years) participated in the experiment. 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 (binocular and with each eye separately) could be measured from 20:200 (low) to 20:15 (high). Muscle balance, indicating a tendency for one eye to drift higher than the other (vertical hyperphoria), for the eyes to cross (esophoria), or for the eyes not to converge at the correct distance (exophoria), was also measured. The muscle balance of every subject was within the normal range.

Prior to experiencing the visual motion, all subjects completed a motion sickness history questionnaire providing details of travel history and previous motion sickness experience (5). Their responses were used to derive motion sickness susceptibility ratings for each subject.

All subjects experienced both the real and the virtual optokinetic drum for up to 30 minutes. Eight subjects commenced with the real drum and eight commenced with the virtual drum. There was at least one week between exposures to reduce effects of habituation. At half-minute intervals during each exposure, subjects provided ratings on a 7-point motion sickness scale (Table 1) and on a 4-point vection scale (Table 2). Following each exposure, subjects completed a symptom checklist, based on that used by Kennedy and Fowlkes (7).

TABLES 1 AND 2 ABOUT HERE

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

### *2.3 Analysis*

The motion sickness ratings were summed over the 30-minute exposure period to give an 'accumulated illness rating' for each subject. 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 ratings were allocated scores: 0 for 'drum only', 1 for 'drum and self intermittent', 2 for 'drum and self continuous' and 3 for 'self only' (see Table 2). The 'accumulated illness ratings' and the 'accumulated vection ratings' were compared across conditions (i.e. between the real and the virtual drums) using the Wilcoxon matched-pairs signed ranks test. Correlations between 'accumulated illness ratings' across conditions, and correlations between 'accumulated vection ratings', 'accumulated illness ratings', past susceptibility to motion sickness and visual acuity within conditions, were determined using Spearman's rank correlation.

Additional analysis was carried out using subject survival times. The time taken for a subject to reach a rating of 2 ("mild symptoms, e.g. stomach awareness but no nausea") on the motion sickness scale was used as the event of interest in this analysis. Initially, Spearman's rank correlation was used to find significant correlations and then Cox regression analysis was used to determine more about the nature of the correlations found. Survival analysis using Cox regression was chosen as it allowed the responses of all subjects to be included in the analysis, taking into account the responses of subjects who did reach a rating of 2 and those who did not. Subject who withdrew from the experiment because of nausea were included without making assumptions about sickness ratings at later times.

### *2.4 Results*

There was no difference in the vection ratings in the two conditions (Wilcoxon, $p>0.10$). However, the accumulated illness ratings (summed over 30 minutes within the two conditions) differed significantly, with mean values of 38.9 in the virtual drum and 54.5 in the real drum (Figure 1, Wilcoxon, $p<0.05$).

FIGURE 1 ABOUT HERE

There was no correlation between the accumulated vection scores and the accumulated illness scores, either in the real drum (Spearman $\rho$ = 0.306, $p$>0.10) or in the virtual drum ($\rho$ = 0.223, $p$>0.10; see Figures 2a and 2b).

There was a significant correlation between the accumulated illness ratings of subjects in the two conditions ($\rho$ = *0.755*, $p$<0.001; Figure 2c). There was also a significant correlation between the accumulated vection scores in the two conditions ($\rho$ = 0.768, $p$<0.001; Figure 2d). These results indicate that subjects who experienced motion sickness in one condition tended to experience motion sickness in the other condition and those who experienced vection in one condition also tended to experience vection in the other.

FIGURE 2 ABOUT HERE

The effect of order of presentation of the two conditions on the motion sickness ratings was tested by comparing the group of 8 subjects who experienced the real drum first with those who experienced the real drum second and, likewise, for those who experienced the virtual drum first and second. These comparisons showed that there was no significant difference between first or second groups in either case (Mann-Whitney U test, $p$>0.10).

*Survival analysis – real drum*

The time taken to reach '2' on the motion sickness scale was defined as the 'survival time'. Initially, the correlation between 'survival time' and several subject characteristics were determined: the subject visual acuity at the near (0.4m) point, acuity at the far point (2.5m) and the rating of susceptibility to motion sickness derived from the motion sickness questionnaire ('total susceptibility to motion sickness', $M_{total}$, as per Griffin and Howarth, (5)). There was a significant correlation between survival time and visual acuity at the near point ($\rho$ = 0.678, $p$<0.01; Figure 2e), with poor acuity being associated with shorter survival times (i.e. earlier onset of sickness). There was no correlation between survival time and visual acuity at the far point ($\rho$ = -0.330, $p$>0.10) or between survival time and past susceptibility to motion sickness ($\rho$

= -0.039, $p>0.10$).

*Survival analysis – virtual drum*

In the virtual reality drum, survival time was again correlated with visual acuity at the near point ($\rho$ = 0.577, $p<0.05$; Figure 2f) but not at the far point ($\rho$ = -0.067, $p>0.10$). There was a marginally significant correlation between past susceptibility to motion sickness and survival time ($\rho$ = -0.437, $p<0.10$).

*Cox's proportional hazards model*

In both the real and the virtual drums, the factor found to significantly influence survival time was visual acuity at the near point (0.4m), with shorter survival times (earlier sickness) among those with poorer acuity. The influence of visual acuity data was investigated further using Cox regression. Visual acuity was expressed in two categories – low (less than 20:20) and high (20:20 or higher). There were 9 subjects with low acuity and 7 subjects with high acuity. A significant influence of visual acuity on survival time was found in both the real drum and in the virtual drum (Cox regression, $p<0.05$). Cox's proportional hazards model results for the real and virtual drums are shown in Table 3. The $e^{\beta}$ values show that a subject in the real drum was 3 times more likely to reach '2' on the motion sickness scale during the 30 minute exposure period if his visual acuity was low (i.e. less than 20:20). Subjects in the virtual drum were nearly 5 times more likely to reach '2' on the motion sickness scale if they had lower than 20:20 vision.

TABLE 3 ABOUT HERE

*Visual acuity and vection*

Individual subject visual acuity scores were not correlated with individual accumulated vection ratings in either the real ($\rho$ = 0.018, $p>0.10$) or the virtual ($\rho$ = -0.070, $p>0.10$) drum. The relation

between vection and acuity could not be investigated in the same way as the relation between motion sickness and acuity (with a Cox regression model) because vection comes and goes during optokinetic stimulation.

### *2.5 Discussion*

Vection and motion sickness scores were not correlated in either condition of the experiment, suggesting that vection may not be the cause of motion sickness. Correlations were found between visual acuity and motion sickness with increased sickness for those subjects with poorer acuity. This is a novel finding and worthy of further investigation.

The correlation between the individual illness ratings given in the two conditions suggests that the virtual reality simulation may be a useful facility for the investigation of visually induced motion sickness. Virtual reality allows greater flexibility in the presentation of moving visual scenes than an optokinetic drum. Overall, the virtual reality simulation generated slightly less sickness than the real drum. This may have been caused by imperfections in the virtual presentation: occasional jumps in the playback of the stripes and some visibly stationary pixels behind white stripes. In the second experiment described below, an improved video interface eliminated the jumps and, with an increase in the brightness of the white stripes, the visibility of stationary pixels was reduced.

## 3. Experiment 2: effect of visual fixation on motion sickness

### *3.1 Introduction*

In the first experiment, subjects with poor visual acuity gave higher illness ratings: an effect that does not appear to have been previously reported. The influence of visual acuity on motion sickness was therefore investigated in a second experiment. It has been suggested that motion sickness is associated with eye movements while vection is associated with movement in the peripheral visual field. The conditions of the second experiment were therefore designed to have

different eye movements, by providing a stationary fixation point while the remaining visual scene moved as in the first experiment. It was hypothesised that the presence of the fixation point would reduce motion sickness but have no effect on vection. Without the fixation point, it was hypothesised that motion sickness would be correlated with visual acuity, as in the first experiment.

### *3.2 Method*

An animation identical to the virtual presentation in Experiment 1 was employed, but presented using an improved video interface to reduce imperfections. Two visual conditions were presented: (i) the optokinetic stimulus used in Experiment 1, and (ii) the same stimulus with a superimposed stationary cross (fixation condition). The two conditions are illustrated in Figure 3. Both conditions were presented using the Virtual Research VR4 head-mounted display. Subject visual acuity was measured as in the first experiment. Eye movements in the horizontal plane were continuously recorded using electro-oculography and acquired to computer using an *HVLab* data acquisition system at 30 samples per second.

FIGURE 3 ABOUT HERE

Eighteen subjects took part in the study, with each subject experiencing both conditions separated by an interval of at least 2 weeks. Nine subjects experienced the ‘fixation’ condition first and the other 9 subjects experienced the ‘non-fixation’ condition first. Of the subjects who participated in experiment 1, four also participated in experiment 2, two of whom had low acuity and two of whom had high acuity The heads of subjects were restrained by the use of a strap attached to the display. Subjects sat in the chair of the optokinetic drum used in Experiment 1, but with the drum in its raised position. Subjects heard white noise through headphones during the presentation, and were spoken to through a microphone each minute. It was possible to check that the eyes of subjects were open by observation from the side of the virtual display: one subject attempted to cheat in this way and was replaced by a different subject. The exposure duration was 30 minutes, with subjects reporting motion sickness symptoms and vection as in

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

### *3.3 Analysis*

The eye movement data were visually inspected. No repetitive eye movements occurred during the fixation condition, indicating that nystagmus (smooth visual pursuit followed by a rapid return saccade) was completely suppressed. In the condition without the fixation cross, a large variability in eye movements was observed between subjects, with high variation in the duration for which nystagmus occurred. Some subjects had periods with no eye movements and other periods when eye movements were typical of tracking the black and white stripes. Nystagmus generally occurred for between 30% and 100% of the exposure when there was no fixation. An approximate percentage time in which nystagmus occurred was found for each subject in the non-fixation condition. The inspection of eye movements was performed without knowing which subject was being analysed.

Motion sickness and vection scores in the two conditions were compared using the Wilcoxon matched-pairs signed ranks test. Spearman's rank correlation was used to investigate relationships between vection, motion sickness, past susceptibility and visual acuity. Survival analysis was performed using Cox regression.

### *3.4 Results*

#### *3.4.1 Motion Sickness*

The mean accumulated illness rating over 30 minutes was significantly less in the fixation condition: 19.4 with fixation compared to 40.7 without fixation (Wilcoxon, $p < 0.01$; Figure 4). Accumulated illness ratings for individual subjects were not significantly correlated between the two conditions ($\rho = 0.445$, $p>0.05$).

FIGURE 4 ABOUT HERE

*Survival analysis – non-fixation condition*

Again, survival time was defined as the time taken to reach '2' on the motion sickness scale. There was a marginally significant correlation between visual acuity at the near point and survival time ($\rho$ = 0.432, $p < 0.10$) with poor acuity being associated with shorter survival times (i.e. earlier sickness). Visual acuity at the far point, and susceptibility to motion sickness, were not correlated with survival time ($\rho$ = 0.186, $p > 0.10$). There was a correlation between the percentage time during which eye movements were observed and survival time ($\rho$ = -0.574, $p < 0.05$): an increase in nystagmus was associated with reduced survival time.

*Survival analysis – fixation condition*

In the fixation condition, survival time was not correlated with visual acuity at the near point ($\rho$ = 0.389, $p > 0.10$) or at the far point ($\rho$ = -0.067, $p > 0.10$). There was a marginally significant correlation between susceptibility to motion sickness and survival time ($\rho$ = -0.437, $p < 0.10$).

*Cox's proportional hazards model*

For the non-fixation condition, Cox regression analysis was performed as in Experiment 1, with two variables: visual acuity at the near point split into high (20:20 or greater) and low (less than 20:20), and the percentage of time during which nystagmus occurred. There were 12 subjects with low acuity and 6 subjects with high acuity. Visual acuity had a significant effect on survival time (Cox regression, $p<0.05$) but the percentage time during which nystagmus occurred was not significant when included in the model with visual acuity (Cox regression, $p > 0.10$).

In the fixation condition, the effect of past susceptibility (the only variable significantly correlated

with accumulated sickness ratings) was investigated in the Cox regression model and found to be significant ($p$<0.01). Table 4 shows the Cox's proportional hazards model for both conditions.

TABLE 4 ABOUT HERE

3.4.1 Vection

Individual subject accumulated vection scores did not correlate with accumulated illness ratings in either the non-fixation condition ($\rho$ = 0.178 p>0.10) or in the fixation condition ($\rho$ = 0.086, $p$ > 0.10).

There was no significant difference in the accumulated vection ratings with or without fixation (Wilcoxon, $p$ > 0.10) or in the time taken to first experience vection (Wilcoxon, $p$ > 0.10). Inspection of the raw results showed that nine subjects reported greater vection with fixation while nine subjects reported greater vection without fixation.

Eye movements during the condition without fixation were compared with vection ratings. There was no apparent difference in vection ratings according to whether the eyes were moving or stationary: vection was reported when the eyes were moving and when the eyes were stationary.

There was a significant correlation between subject accumulated vection ratings in the two conditions ($\rho$ = 0.674, $p$ < 0.01), indicating that those subjects who experienced vection without fixation also experienced vection with fixation, even though eye movements only occurred without fixation.

### 3.5 *Discussion*

A reduction in sickness with fixation, and a reduction in survival time with increased duration of eye movements in the non-fixation condition, is consistent with reductions in eye movements or reduction in foveal stimulation, reducing motion sickness. In the non-fixation condition, during periods with no eye movements, subjects may have been looking at a particular area of the

display (perhaps the edge of the screen rather than the image on the display) or 'gazing through' the display.

In the Cox regression model, visual acuity was found to be a more important predictor of motion sickness than the duration for which eye movements occurred, possibly indicating that visual acuity influenced the nystagmus.

Although visual fixation reduced motion sickness it did not affect vection. This suggests that vection does not have a large influence on motion sickness with this type of moving visual scene. It also suggests that vection was not greatly influenced by eye movements. This is consistent with vection being mainly determined by motion in the periphery of the visual field.

Although there was a correlation between accumulated vection ratings in the two conditions (i.e. with and without fixation), there was no correlation between accumulated illness ratings in the two conditions. This, again, is consistent with vection being influenced by peripheral vision and motion sickness being influenced by either foveal vision or eye movements.

There was no correlation between ratings of vection and sickness, either with or without fixation. Some subjects reported high levels of sickness without reporting vection.

# 4 Discussion and Conclusions

An aim of this study was to investigate the possible correlations between vection and motion sickness in response to optokinetic stimuli. Vection and motion sickness were measured separately in each of four conditions in the two experiments. There were no significant correlations between the vection scores and motion sickness scores. Motion sickness varied significantly between the normal and fixation conditions of experiment two but vection was not significantly different between these conditions. The lack of significant correlations between vection and motion sickness and the ability to vary motion sickness without influencing vection suggest that vection and motion sickness may be separate phenomena. They often occur together but can be varied independently depending on the properties of the visual display and

the nature of the task.

Stern *et al.* (11) reported a reduction of motion sickness with visual fixation, consistent with the results of the second experiment reported here. They also found a slight reduction in vection with fixation, which is inconsistent with the present experiment in which a smaller field of view was employed. Stern *et al.* (11) did not comment on the correlations between vection and motion sickness scores. Previous literature on motion sickness and vection has failed to show significant correlations between motion sickness and vection. In some cases (e.g. Hettinger *et al.,* (6)) the condition with the highest rating of vection also had the highest incidence of motion sickness. This falls short of showing that there is a correlation between vection and motion sickness. In future experiments, it would seem wise to measure both vection and motion sickness and not assume that variations in vection will result in similar variations in motion sickness.

The second experiment presented here found that visual acuity influenced motion sickness when there were eye movements. This suggests that motion sickness may be influenced by eye movements, motion detection in the fovea (foveal slip), or both. With fixation, when there were no eye movements and image motion occurred over the peripheral retina, there was no image motion at the fovea. The lack of association between visual acuity and motion sickness in the fixation condition allows the possibility that motion detection on the fovea, which may be influenced by visual acuity, might affect motion sickness. This would be consistent with previous research, which has shown a foveal dominance in the slow phase velocity of optokinetic nystagmus (7, 12).

Ratings of past susceptibility to motion sickness were not significantly correlated with ratings of sickness in any of the conditions investigated, except for the fixation condition of Experiment 2. Possibly, factors related to visual acuity had such a strong influence on motion sickness when there was motion in the central visual field that other factors contributing to susceptibility to motion sickness (as evidenced by a history of motion sickness in common environments) only had a detectable effect when the influence of visual acuity was diminished by fixation. Visual

acuity may not have such a dominant effect on susceptibility to motion sickness: the subjects who had poor visual acuity in the experiments had near normal acuity when wearing spectacles or contact lenses during daily life.

The results of this study do not indicate what role is played by vestibular function in the causation of motion sickness and vection associated with optokinetic stimulation. Further work will be needed to investigate such factors and integrate the findings into a model of visual-vestibular interaction.

The correlation in subject motion sickness scores between the optokinetic drum and the virtual reality presentation of the optokinetic drum suggest that this type of motion sickness experiment can be undertaken using virtual reality, and the results compared with previous studies using optokinetic drums.

# 5 References

1. Brandt TH, Dichgans J, Koenig E. Differential effects of central versus peripheral vision on egocentric and exocentric motion perception. Experimental Brain Research 1973, 16, 476-491.

2. Cheung BSK, Howard IP, Money KE. Visually induced sickness in normal and bilaterally labyrinthine-defective subjects. Aviation, Space and Environmental medicine 1991; 62, 527-31.

3. Ebenholtz SM, Cohen MM. The possible role of nystagmus in motion sickness: a hypothesis. Aviation, Space and Environmental Medicine 1994; 65, 1032-1035.

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

5. Griffin, MJ, Howarth HVC. Motion sickness history questionnaire. ISVR Technical Report No. 283, 2000. University of Southampton, Southampton, England.

6. Hettinger LJ, Berbaum KS, Kennedy RS, Dunlap WP, and Nolan MD. Vection and simulator sickness. Military Psychology 1990; 2(3), 171-181.

7. Howard, IP, Ohmi, M The efficiency of the central and peripheral retina in driving human optokinetic nystagmus. Vision Research 1984; vol.24 (9), 969-976.

8. Hu S, Davis M.S, Klose AH Effects of spatial frequency of a vertically striped rotating drum on vection induced motion sickness. Aviation, Space and Environmental Medicine 1997; 68 (4) 306-311.

9. Johnson WH, Sunahara,F.A., Landolt,J.P. Importance of the vestibular system in visually induced nausea and self-vection. Journal of Vestibular Research 1999; 9 (2), 83-87.

10. Kennedy RS and Fowlkes JE. Simulator sickness is polygenic and polysymptomatic: implications for research. International Journal of Aviation Psychology 1992; 2(1), 23-38.

11. Stern RM, Hu S, Anderson RB, Leibowitz HW and Koch KL. The effects of fixation and

restricted visual field on vection-induced motion sickness. Aviation, Space and Environmental Medicine 1990; 61 (8), 712-715.

12. Van Die GC, Collewijn H Control of human optokinetic nystagmus by the central and peripheral retina: effects of partial field masking, scotopic vision and central retinal scotomata. Brain Research 1986; 383, 185-194.

**Table 1.** Illness rating scale (adapted from Golding and Kerguelen, 1992.)

| Subjective Response | Corresponding Feeling |
|---|---|
| 0 | No symptoms |
| 1 | Any symptom, 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 |

**Table 2.** Vection rating scale.

| Perception of what is moving | Meaning |
|---|---|
| Drum Only | You perceive that the only thing moving is the drum (real or virtual). |
| Drum and Self (intermittent) | You perceive the drum to be moving but also experience periods of self motion. |
| Drum and Self (continuous) | You perceive the drum to be moving and simultaneously experience continuous self motion. |
| Self Only | You perceive the drum to be stationary and experience continuous self motion only. |

**Table 3.** Cox proportional hazards model for Experiment 1: real and virtual drums.

| Condition | Independent variables | $e^{\beta}$ | Significance ($\beta$) |
|---|---|---|---|
| Real drum | Visual acuity at the near point in two categories – high (>=20:20), low (<20:20). | 3.0555 | 0.0436 |
| Virtual drum | Visual acuity at the near point in two categories – high (>=20:20), low (<20:20). | 4.9137 | 0.0476 |

**Table 4.** Cox proportional hazards model for Experiment 2: non-fixation and fixation conditions.

| Condition | Independent variables | $e^{\beta}$ | Significance ($\beta$) |
|---|---|---|---|
| Non-fixation condition | Visual acuity at the near point in two categories – high (>=20:20), low (<20:20). | 5.1058 | 0.0358 |
| Fixation condition | Past susceptibility to motion sickness, $M_{total}$. | 1.0624 | 0.0098 |

FIGURE CAPTIONS

1. Average motion sickness ratings with the real and virtual drum in Experiment 1 (motion sickness ratings in the real drum are greatest).
2. Correlations between accumulated illness ratings, accumulated vection ratings, visual acuity and survival times in Experiment 1.

   2.a. Accumulated illness ratings and accumulated vection ratings in the real drum.

   2.b. Accumulated illness ratings and accumulated vection ratings in the virtual drum.

   2.c. Accumulated illness ratings in the real drum and in the virtual drum.

   2.d. Accumulated vection ratings in the real drum and in the virtual drum.

   2.e. Visual acuity and survival time in the real drum. (Acuity is expressed as a percentage where 20:20 is 100%; higher percentages correspond to better acuity).

   2.f. Visual acuity and survival time in the virtual drum. (Acuity is expressed as a percentage where 20:20 is 100%; higher percentages correspond to better acuity).
3. The non-fixation and fixation conditions of Experiment 2. In the fixation condition subjects focused on the stationary cross while the stripes moved behind the cross.
4. Mean accumulated illness ratings for the non-fixation condition and the fixation condition in Experiment 2.

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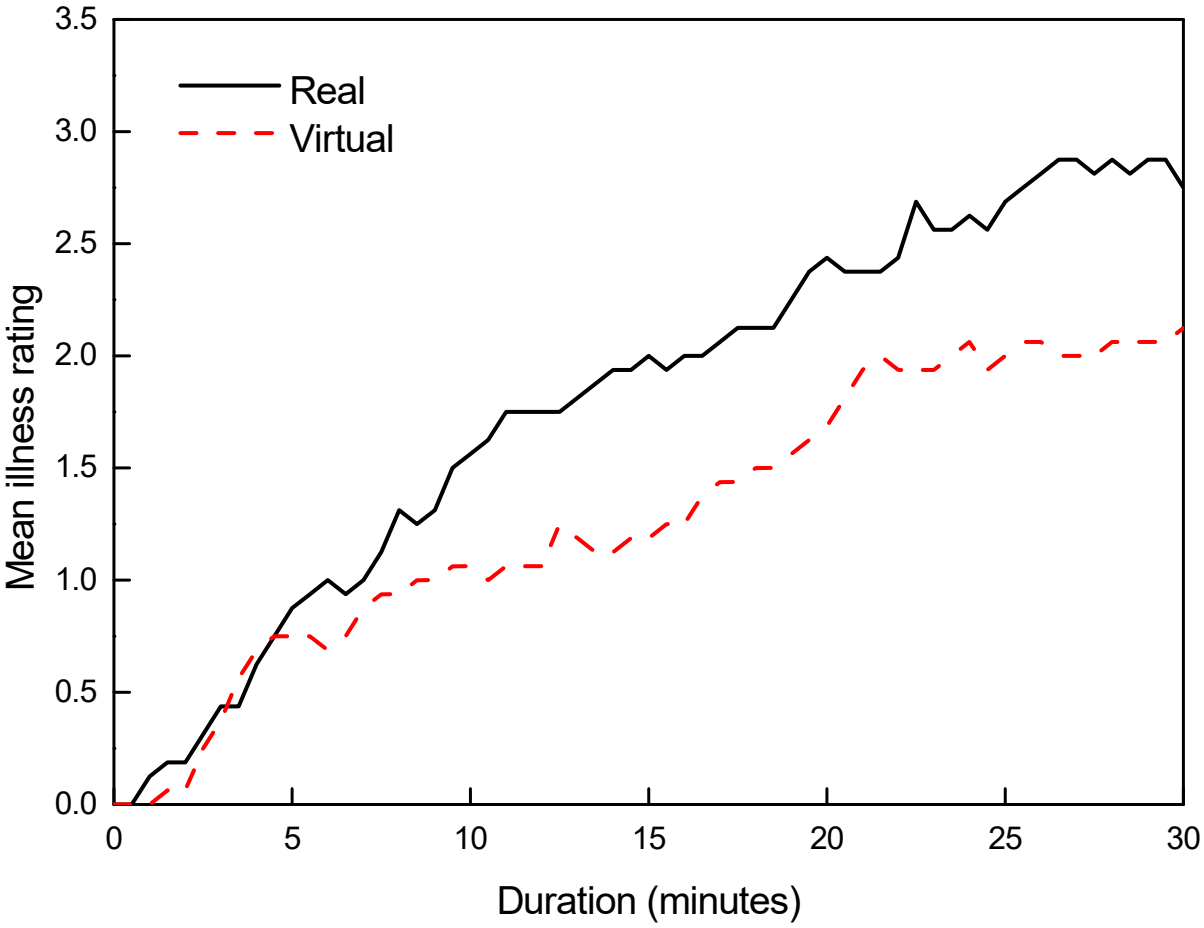


Figure 1 Average motion sickness ratings with the real and virtual drum in Experiment 1 (motion sickness ratings in the real drum are greatest).

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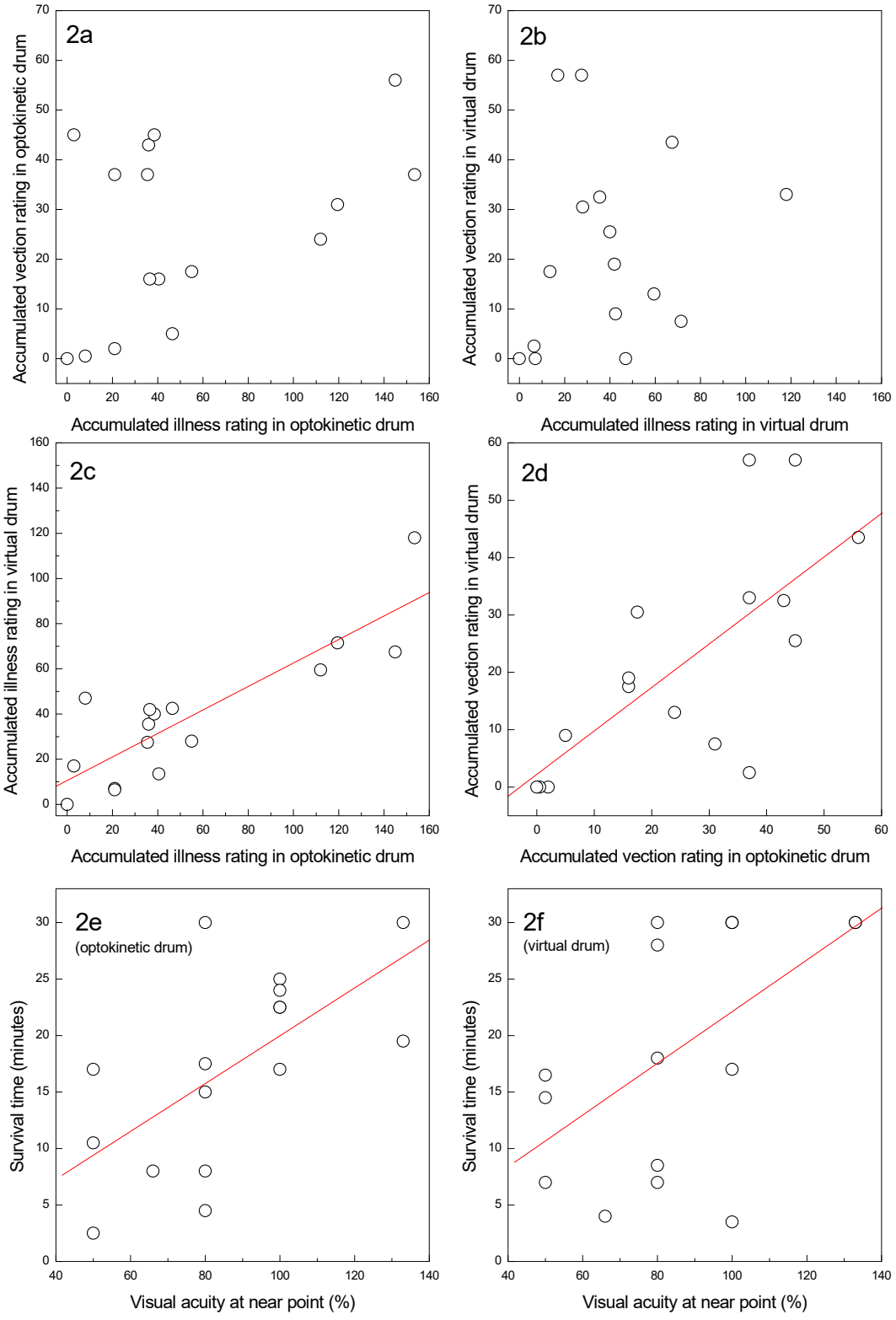

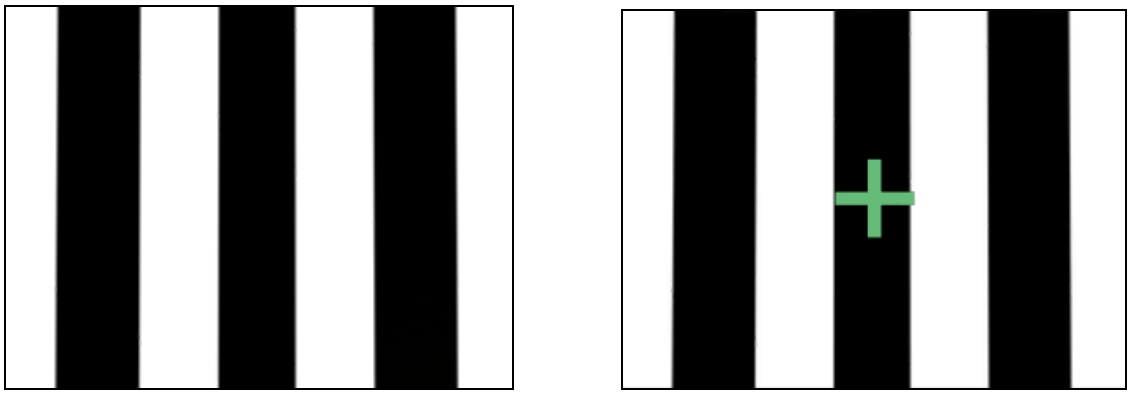

Figure 3 The non-fixation and fixation conditions of Experiment 2. In the fixation condition subjects focused on the stationary cross while the stripes moved behind the cross.

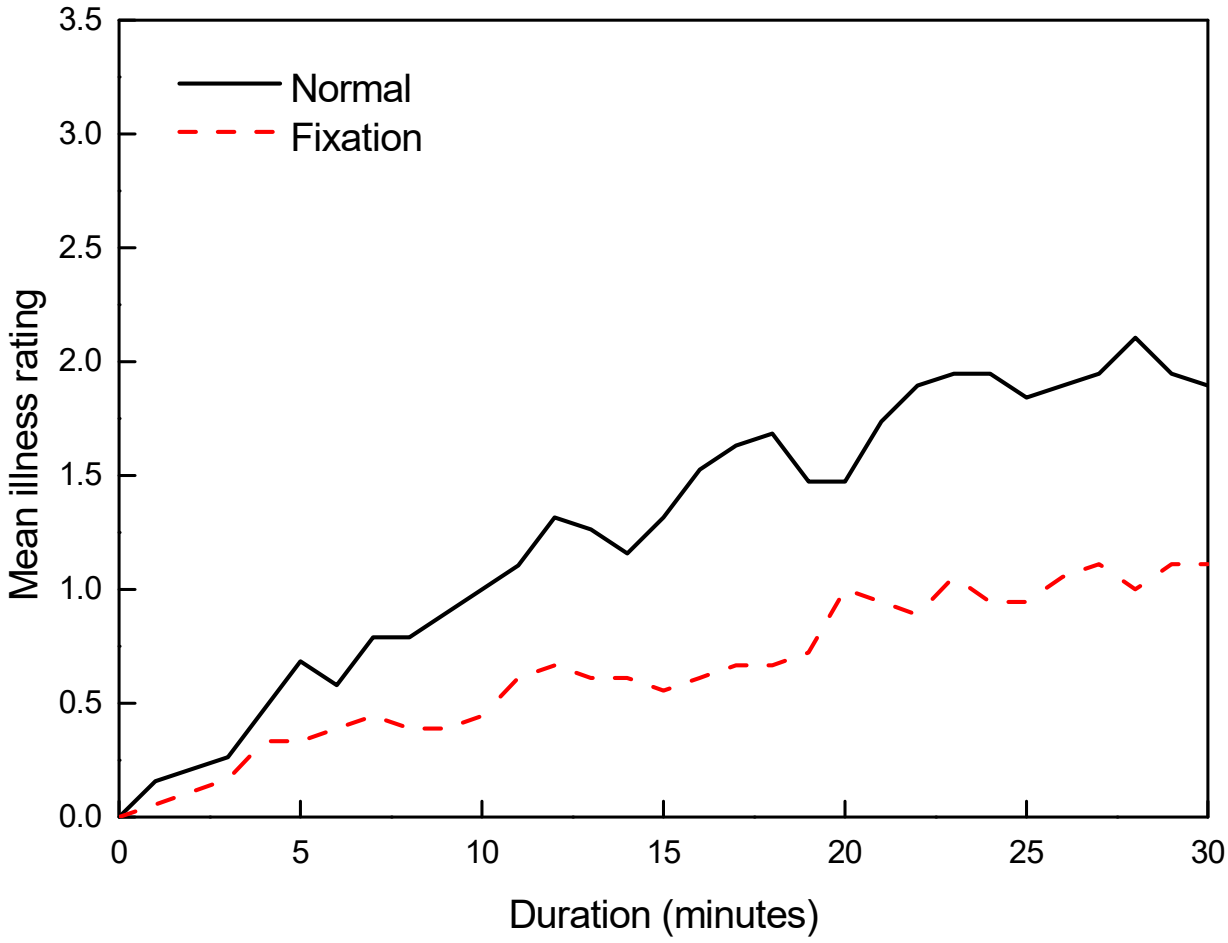


Figure 4 Mean accumulated illness ratings for the non-fixation condition and the fixation condition in Experiment 2.