The effects of frequency and tilt on motion sickness induced by optokinetic stimuli

John F. Golding [1,2], Smitha Arun [1], Elizabeth Wortley [2], Kahina Wotton-Hamrioui [2], Michael A. Gresty [2] .

[1] Dept. Psychology, University of Westminster, Regent Street, London W1B 2UW, UK.

[2] Division of Neuroscience and Psychological Medicine, Imperial College, Charing Cross Hospital, London, W6 8RF, UK.

[1]goldinj@wmin.ac.uk m.[2]gresty@imperial.ac.uk

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Abstract. ***Background*** Nauseogenicity is determined by exposure time, frequency and acceleration of real motion. Our aim was to determine the nauseogenicity of these parameters for the optokinetic equivalent of OVAR (Off Vertical Axis Rotation). ***Methods*** The visual stimulus was a computerised scene of coastline as seen by a 'pilot' at moderate altitude. The scene could be rotated at different frequencies and tilted, just as during OVAR. The projected image subtended 84º at the eyes and subjects performed a concurrent task of detecting occasional visual targets to control attention. Exposures were for 10min or until nausea developed. Design was repeated measures counterbalanced for order. Optokinetic nauseogenicity was determined in three experiments: 0.05, 0.2, 0.8 Hz all at 18º tilt (n=14); 0, 45, 90º tilts all at 0.2Hz (n=12); 18, 36, 54, 72 º tilts all at 0.2Hz (n=24). ***Results*** 0.2 Hz was more nauseogenic than lower 0.05 or higher 0.8 Hz frequencies ($p<0.01$); 18 to circa 45º tilts were most nauseogenic ($p<0.01$). For all experiments symptoms usually increased over time. ***Conclusions*** The nauseogenicity peak around 0.2Hz, and increase with stimulus 'strength' up to circa 45º tilt, are similar for optokinetic and real motion. However, decreasing nauseogenicity with even higher tilt angles suggests that the impact of virtual stimuli is partially 'quarantined', perhaps because they appear obviously 'absurd', and therefore no longer present a sensory conflict that has to be resolved.

Introduction

Nauseogenicity of real translational motion increases with exposure duration and acceleration and peaks around a frequency of 0.2 Hz (Lawther & Griffin, 1987; O'Hanlon & McCauley, 1974; Golding et al, 2001). Off vertical axis rotation (OVAR) has some similarities to provocative translational motion except that the acceleration stimulus is the gravity vector rotating with respect to the long axis of the head-body, the magnitude being determined by the angle of tilt. The peak frequency for OVAR nauseogenicity has been estimated to be around 0.2 Hz (Miller & Graybiel, 1973) although one experiment suggested a slightly higher peak around 0.3 Hz (Denise et al, 1996). Motion sickness (MS) susceptibility has also been shown to increase dramatically with increasing angle of off-vertical tilt (Miller and Graybiel, 1973). An increase from 2.5º to 25º of tilt decreases the time to onset of moderate nausea from 60 minutes to just 6 minutes. OVAR studies tend not to use angles of tilt beyond 30º, partly because of additional technical difficulties but mainly because the stimulus is so extremely nauseogenic. For example with a tilt of 90º, 12 out of 20 subjects rotated about earth-horizontal through the z-axis of the body were unable to complete a very short 2 minute exposure due to severe nausea (Correia & Guedry, 1966). This so-called 'barbecue-spit'

rotation is such a notoriously unpleasant stimulus that historically it was used as a form of punishment (Reason and Brand, 1975; Harsch, 2006). Tilt of the head away from the axis of body rotation can also rapidly evoke MS. This activates more than one pair of semicircular canals at once, evoking a perception of self-tilt. This is known as coriolis or cross-coupling (Benson, 1999). Transient tilts of rotating visual motion can also provoke MS. Pseudo-coriolis is the visual equivalent to coriolis, occurring when the head is tilted away from the axis of rotation during circular vection. As with coriolis, the resulting sensation of self-tilt provokes MS (Eyeson-Annan et al, 1996).

Many studies have shown that visual motion alone can induce symptoms of MS. Stimuli used include optokinetic drums, rotating spheres and computer generated scenes (Bubka & Bonato, 2003; Cheung, Howard, Money, 1991; Isu, Matsumoto & Aoki, 2000). In all of these studies the visual input induces vection. Prolonged vection has been correlated with simulator sickness (Hettinger, Berbaum, Kennedy, 1990) although the relationship between motion sickness and vection is not absolute (for review see Lawson, 2006). An everyday example of visually evoked MS is the widescreen cinema. Many people experience vection when watching a large screen, and certain types of on-screen motion have been known to induce nausea in unsuspecting cinema-goers.

MS susceptibility can be influenced by an element of either physical or perceived self-tilt during both linear and angular acceleration (Golding et al, 2003). A 'real-life' example is the tilting train which, unlike conventional trains, can be very nauseogenic. When tilting trains round bends they tilt into the curve (rather than outwards). As a consequence the coaches, and passengers within, remain inertially upright while the world seen through the window appears to tilt downwards. MS here is thought to be visually-evoked, specifically via visual-inertial and visuo-vestibular conflict, demonstrated by a substantial decrease in sickness when the view is excluded. (Neimer et al, 2001). This is further supported by correlation between MS provoked by oblique optokinetic stimuli and tilting train sickness.

Relatively few data are available as to the effects of frequency on nauseogenicity of optokinetic drum stimulation, Hu et al (1989) found that a rotational frequency of 0.17 Hz was most provocative. A recent study of the effect of tilts of 0^o, 5^o and 10^o of an optokinetic drum rotating about earth-vertical showed that increasing tilt of the drum hastened onset of MS (Bubka & Bonato, 2003). However this did not investigate angles of tilt greater than 10^o and the study of Eyeson-Annan et al (1996) did not exceed a drum tilt of 20^o. Therefore this study aims to determine the effect of different angles of tilt of a rotating visual scene on MS susceptibility. A coloured pattern is a stronger stimulus than a black and white one (Bonato et al, 2003) and we employed a full colour scene in the present study. A realistic scene was used because the richness of visual simulation is positively correlated with MS (Kennedy & Fowlkes, 1992).

Our aim was to determine the effects on nauseogenicity of tilt (function of rotating gravitation acceleration magnitude), exposure duration and frequency for the optokinetic equivalent of OVAR (Off Vertical Axis Rotation).

Methods

Methods common to all Experiments 1, 2 & 3.

Visual(Optokinetic)Stimulus (Experiments 1, 2 & 3). A computer generated scene depicted a view over the sea from above a coastline (the world as it might be seen from the canopy of an aircraft at moderate altitude). The scene could be rotated at a variety of frequencies and could rotate at any angle of tilt from 0^o, in which the horizon was parallel to the floor, to 90^o in which the horizon was aligned with earth-vertical. The scene was projected onto a large screen 2m by 2m in size, with the

image extending to the edges of the screen. A comfortable supportive chair was positioned centrally in front of the screen such that, when seated, the distance between the participant's eyes and the screen would be 1.12m. (Figure 1). The participant wore goggles designed to restrict their field of view to 84°. This excluded peripheral vision of the stationary laboratory. A simple visual vigilance task was used in order to control the attention of the subject. A laser dot was displayed briefly on the screen at random intervals and different locations, the subject was asked to count the number seen and this was checked at the end of each condition of optokinetic stimulation.

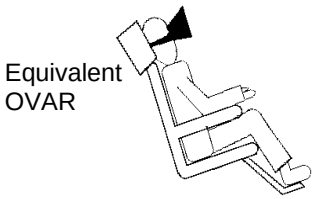

Figure 1. (Top left) The subject sat 112cm in front of the screen wearing goggles. This ensured that the entire visible visual field is moving. The picture on the screen was tilted at different angles (36° is shown here) and rotated about the yaw axis (z-axis). (Lower) View of the picture as seen by the subject, shown here from a perspective that has an 18° vertical tilt. The equivalent OVAR is shown (top right.

Sickness Ratings & Symptom Checklist (Experiments 1, 2 & 3). The participant was familiarised with the following subjective sickness rating scale: 1=no symptoms; 2=initial symptoms of MS but no nausea; 3=mild nausea 4=moderate nausea; 5=severe nausea and/or retching; 6=vomiting (Golding et al, 2001). The participant was asked to report sickness rating every minute during optokinetic stimulation. In experiments 1 and 2, trials were terminated when the participant reached sickness rating 4 (SR=4) or 10 minutes had elapsed whichever was the sooner. In experiment 3, SR=3 or 10 minutes maximum exposure, was taken as endpoint in order to reduce the possibility of carry-over between the large number of trials (see experiment 3). The participant continued to report sickness ratings during recovery at 1,2,3,4,5 and 10 minutes after visual-motion endpoint. Immediately before and after each trial the subject was

rated on a symptom checklist (Golding et al, 2001). The following symptoms were listed: dizziness, bodily warmth, headache, sweating, stomach awareness, increased salivation, nausea, pallor (experimenter-rated). Any additional symptoms were noted. Symptoms were scored in the following way: nil=0; mild=1; moderate=2; severe=3. The checklist at visual-motion endpoint was scored and the total taken as the 'total symptom score'. Motion Sickness Susceptibility was estimated by a validated questionnaire, the MSSQ-short (Golding, 2006a).

Subjects (Experiments 1, 2 & 3). Participants were healthy volunteers, with fully functioning vestibular system and vision (allowed to wear spectacles if usually worn), and not on any current medication. They were fully briefed, gave informed consent and were free to withdraw at any time. Ethical approval was granted by the local Ethics Committees of the University of Westminster and Imperial College. Other details are given in each experiment.

Statistical Analysis (Experiments 1, 2 & 3). Due to non-normal distributions of the data, especially caused by right-censoring where subjects reached maximum time of 10 minutes before achieving all sickness levels, non-parametric tests were used. These were Friedman ANOVA and where relevant for specific comparisons, the Wilcoxon test.

Methods Experiment 1.

Design Experiment 1. Subjects were exposed to the optokinetic stimulus at 18 ^{o} tilt angle, at frequencies 0.05 Hz, 0.20 Hz, 0.80 Hz, i.e. two octave steps. Order of presentation was according to replicates of a Latin Square balanced for carry-over. The three conditions were presented in succession in the same session, with 10 minute washout periods between conditions. This allowed any MS symptoms from the previous condition to subside before exposure to the next condition.

Subjects Experiment 1. Participants (n=14) were 3rd year university students with ages ranging between 20 and 26, (M = 20.9 SD = 1.7 years) of which 11 were females and 3 were males. Their range of percentiles on the Motion Sickness Susceptibility Questionnaire was 10 – 75, mean 30.75 ± 20.32. indicating that the sample was slightly less susceptible than the norm which is 50% by definition:

Results Experiment 1. One subject became very sick in the 0.2 Hz condition and withdrew before completing all the other conditions. His data were therefore deleted since there was insufficient comparison data available at other frequencies. No order effects were found for any variable, suggesting that habituation or sensitisation did not occur. Results are shown in Table 1 and Figs 2 and 3. ANOVA of time to sickness rating =2 (X^2 = 10.9, df = 2, n=13, p = 0.004), sickness rating =3 (X^2 = 7.4, df = 2, n=13, p = 0.024) and sickness rating =4 (X^2 = 6, df = 2, n=13, p = 0.05) were significant. ANOVA for Total Symptom Scores at endpoint was also significant (X^2 = 6.5, df = 2, n=13, p = 0.038). Table 1 and Figs 2 & 3 indicate that the source of these effects were the shorter times taken to become motion sick at 0.2 Hz.

Table 1. Summary Results for Experiment 1. Numbers achieving each Sickness rating stage, and mean ± SD of other variables.

	0.05Hz	0.20Hz	0.80Hz
N to SR= 2	7/13	11/13	5/13
N to SR= 3	0/13	4/13	2/13
N to SR= 4	0/13	3/13	0/13
Time to reach SR=2 (mins)	8.15 ± 3.89	4.31 ± 3.72	7.77 ±4.51
Time to reach SR=3 (mins)	10 ± (0)	8.46 ± 4.01	9.92 ± 2.75
Time to reach SR=4 (mins)	10 ± (0)	9.54 ± 3.18	10 ± (0)
Total symptom score	1.46 ± 1.66	3.62 ± 2.90	2.69 ± 3.12

Table note: n=13 is shown since one subject withdrew from the 0.2 Hz condition due to excessive sickness and before completing all other conditions

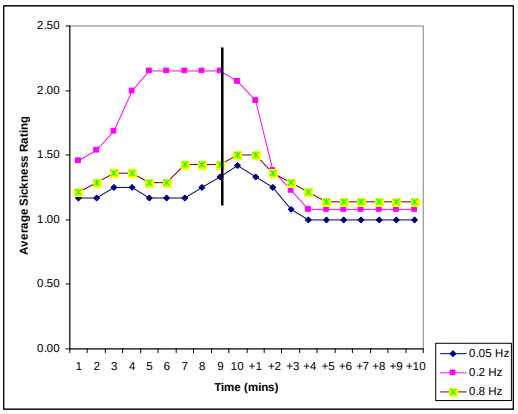

Figure 2. In Experiment 1, the time to Sickness Rating 2, 3 and 4 was significantly faster at 0.2Hz than at 0.05Hz or 0.08Hz. Note that 0.2Hz was the most provocative frequency for inducing MS.

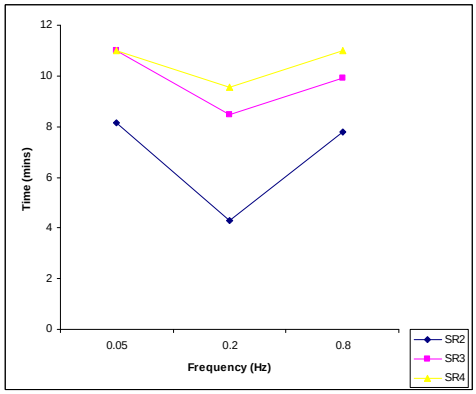

Figure 3. Average sickness ratings during exposure and also during the recovery period are shown for Experiment 1. For subjects who reached SR=4 before the 10 minute maximum exposure time, continuation points of SR=4 were inserted for illustration purposes. The sickness rating after the 10min cut-off time is the point at which the recovery period starts and is indicated by the vertical bar.

Methods Experiment 2.

Design Experiment 2. Twelve participants were exposed to visual scene rotation at 0.2 Hz at three angles of tilt: 0°, 45° and 90° . Conditions were assigned according to Latin Squares balanced for carry-over. The three conditions were presented in succession in the same session, with 10 minute washout periods between conditions. This allowed any MS symptoms from the previous condition to subside before exposure to the next condition.

Subjects Experiment 2. The twelve healthy participants (two men and ten women) were aged ranging from 18-26 years, mean age (+/-SD) was 21.67 (1.78). Potential participants reporting no history of susceptibility to MS were excluded. Participants' motion sickness susceptibility mean percentile (+/-SD) scores were 72.08% (+/- 30.71%). This indicated that the sample was more MS susceptible than the normal population, where a mean percentile of 50% is expected.

Results Experiment 2. Mean time to SR=2, SR=3 and SR=4 for each angle are presented in Table 2. Friedman ANOVAs performed on time to SR=3 and SR=4 at 0°, 45° and 90° showed significant angle effects. Time to SR=3 showed a significant angle effect (Friedman, χ^2=6.95, n=12, df=2, p<0.05). Time to SR=4 showed a marginally significant angle effect (Friedman, χ^2=4.53, n=12, df=2, p<0.1). Total Sickness Scores at endpoint were marginally different across angles (Friedman, χ^2=5.8, n=12, df=2, p=0.054), although the specific comparison of 45 with 90 degree was significant (Wilcoxon z=2.4, n=12, p<0.05). Mean SRs at 1,2,3,4,5,6,7,8,9 and 10 minutes during trials are presented in Figure 3. It is evident that the 90° condition resulted in the lowest scores across the 10 min, whereas the 45° condition yielded the highest scores.

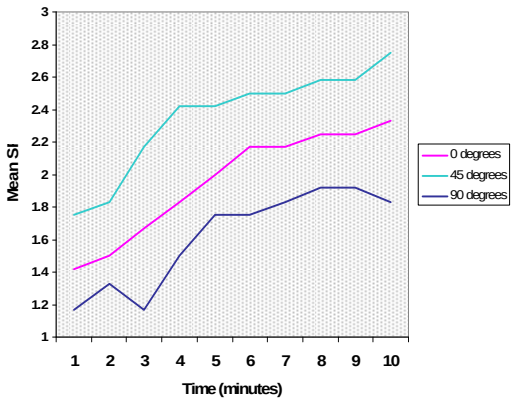

Figure 4. Mean Sickness ratings (SR) are shown every minute over the time course of the 10 minute trials for 0°, 45° and 90° of tilt in Experiment 2.

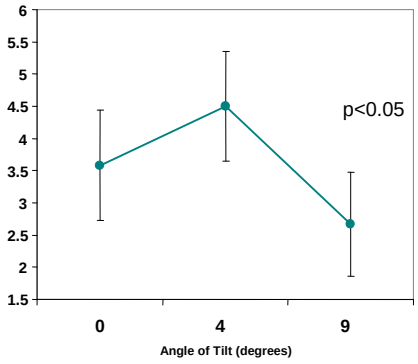

Figure 5. Mean Total Symptom Scores at motion endpoint for 0°, 45° and 90° of tilt in Experiment 2. Total Symptom Scores were higher at 45° than at 90° of tilt.

Methods Experiment 3.

Design Experiment 3. Twenty four participants were exposed to visual scene rotation at 0.2 Hz at four angles of tilt: 18°, 36°, 54° and 72° . Order of tilt angle conditions were assigned according to Latin Squares balanced for carry-over. To reduce the possibility of carry-over of residual motion sickness symptoms beyond each 10 minute wash-out, because of the increased number of nauseogenic conditions, each trial was halted when the participant reached mild nausea SR=3 or when 10 minutes had elapsed.

Subjects Experiment 3. The n=24 (fifteen women and nine men) participants ranged from 19-28 years of age, mean age (+/-SD) was 22.29 (1.94). Potential volunteers who reported no history of motion sickness were excluded. The mean MSSQ percentile score (+/-SD) was 81.88% +/- 15.02%. This indicates that the sample was substantially more MS susceptible than the normal population.

TABLE 2. NUMBERS REACHING EACH SICKNESS RATING (SR) STAGE , MEAN (SD) TIME IN MINUTES TO ACHIEVE EACH SR STAGE AND TOTAL SYMPTOM SCORE AT ENDPOINT, BY ANGLE OF TILT, IN EXPERIMENT 2.

	0°	45°	90°
N reaching SR=2	9/12	11/12	9/12
N reaching SR=3	4/12	5/12	2/12
N reaching SR=4	2/12	5/12	2/12
Time to SR=2 Initial Symptoms	4.1 (3.8)	2.6 (2.9)	4.6 (3.5)
Time to SR=3 Mild Nausea	8.5 (2.7)	6.9 (4.3)	9.3 (1.8)
Time to SR=4 Moderate Nausea (endpoint)	9.2 (2.3)	8.0 (2.8)	9.9 (0.4)
Total Symptom Score	3.6 (3.0)	4.5 (2.9)	2.7 (2.8)

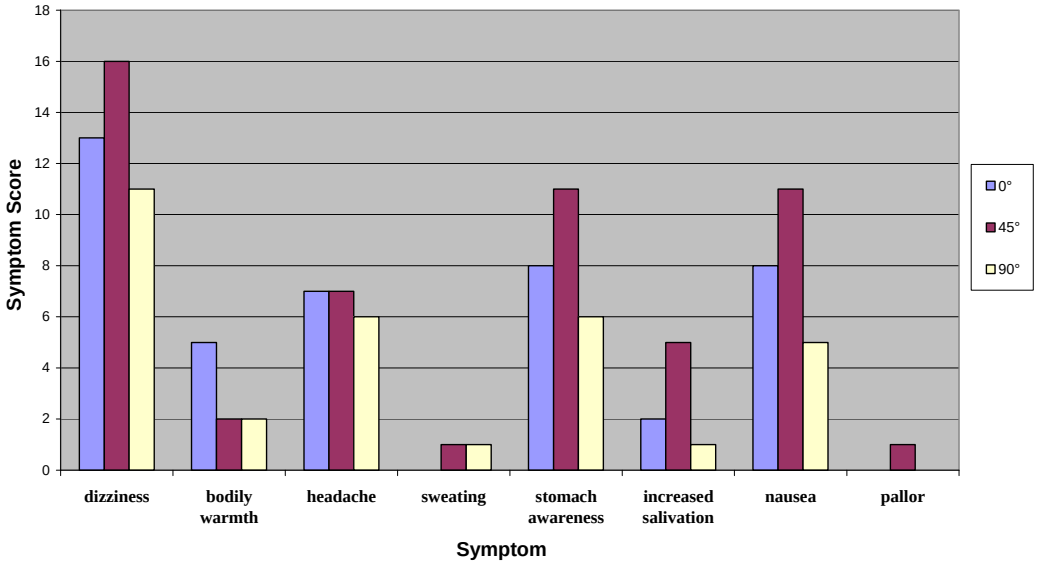

Figure 6. Bar chart showing scores at motion endpoint for individual symptoms at tilt angles 0°, 45° and 90° in Experiment 2.

Results Experiment 3. No significant condition order effects were found. Mean time to SR=2 and SR=3 for each angle are presented in Table 3. Friedman ANOVAs performed on time to SR=2 and SR=3 at 18°, 36°, 54° and 72° showed angle effects. Time to SR2 showed a marginally significant angle effect (Friedman, χ^2=11.80, n=24, df=3, p<0.1). Time to SR3 showed a significant angle effect (Friedman, χ^2=11.64, n=24, df=3, p<0.01). The Total Symptom Scores at motion endpoint for the three angles of tilt are presented in Figure 8. Friedman ANOVAs performed on Total Symptom Scores at 18°, 36°, 54° and 72° showed significant angle effects (Friedman, χ^2=9.80, n=24, df=3, p<0.05). Inspection of Figure 8 indicates that these effects are due to subjects suffering fewer symptoms at 72° than at 18°, 36° and 54°. Additionally, the majority of subjects spontaneously reported vection in the 18°, 36° and 54° conditions, whilst only a few reported vection at 72°.

TABLE 3. NUMBERS REACHING EACH SICKNESS RATING (SR) STAGE , MEAN (SD) TIME IN MINUTES TO ACHIEVE EACH SR STAGE AND TOTAL SYMPTOM SCORES AT ENDPOINT, BY ANGLE OF TILT, IN EXPERIMENT 3				
	18°	36°	54°	72°
N reaching SR=2	22/24	23/24	24/24	21/24
N reaching SR=3	16/24	11/24	15/24	10/24
Time to SR=2 Initial Symptoms	2.5 (2.5)	2.6 (2.3)	2.1 (1.7)	4.0 (2.9)
Time to SR=3 Mild Nausea	6.6 (2.8)	7.9 (2.9)	7.2 (2.6)	8.9 (1.8)
Total Symptom Scores at endpoint	6.2 (3.4)	6.8 (3.8)	7.0 (3.8)	4.9 (3.2)

Table note: stimulation was terminated at SR=3 in order to avoid carry-over of motion sickness beyond the 10 minute wash-out periods, owing to the additional number of potentially nauseogenic conditions in Experiment 3.

The evolution over time of sickness ratings at 1,2,3,4,5,6,7,8,9 and 10 minutes during each tilt condition and at 1,2,3,4, and 5 minutes during recovery are presented in Figure 7. It is evident that the 72° condition resulted in the lowest scores across the 10 minutes.

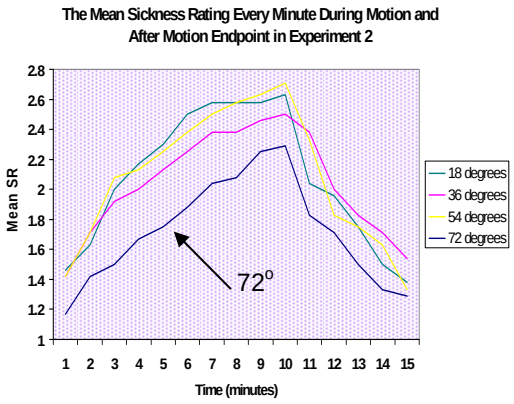

Figure 7. Mean sickness rating are shown for Experiment 3 during motion (minutes 1 to1 to 10) and for the first 5 minutes of the recovery period (11 to 15 minutes in the fig.) for angles of off-vertical tilt: 18°, 36°54° and 72°. The tilt of 72° was less provocative of MS at all time-points.

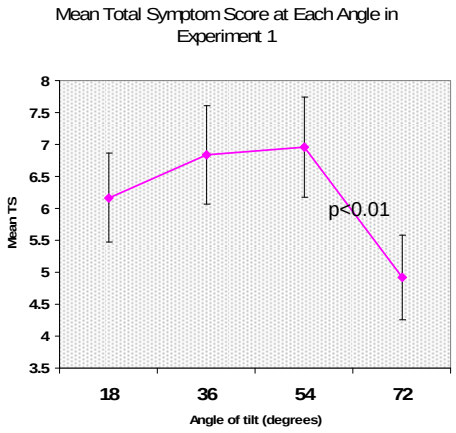

Figure 8. Mean Total Symptom Scores at motion endpoint for 18°, 36°, 54° and 72° of tilt in Experiment 3. Total Symptom Scores dropped significantly when tilt angle increased above 54° to 72° of tilt.

Post hoc comparisons between angles using Wilcoxon signed-ranks tests revealed that Total Symptom Scores were significantly higher for 54° than 72°, ($z=2.65$, $n=24$, $p<0.01$) and time to SR3 was significantly shorter for 54° than 72° ($z= 2.6$, $n=24$, $p<0.01$). There were no significant differences between 18°, 36°, and 54° for any of the measures. These results indicate a decreased sensitivity to 72° of tilt of rotating visual motion.

Discussion

The aim of these experiments was to determine the effects on nauseogenicity of the variables frequency, acceleration (i.e. tilt to earth vertical) and exposure duration for the optokinetic equivalent of Off Vertical Axis Rotation (OVAR).

A previous study of the nausea effects of an optokinetic drum suggested a peak at 0.17 Hz (Hu et al, 1989). For rotational visual motion about the long axis of the body and at 18 ^{o} tilt to earth-vertical, the present study demonstrated that nauseogenicity was maximal at 0.2 Hz as compared to frequencies spaced two octaves above and below this. These are consistent with data for real motion (Miller & Graybiel, 1973; Lawther & Griffin, 1987; O'Hanlon & McCauley, 1974; Golding et al, 2001). Various explanations have been proposed including frequency dependent phase differences between different sensory systems (von Gierke & Parker, 1994; Benson, 1999; Denise et al, 1996) or the perceptual vertical (Bles et al, 1998) and so-called 'tilt-translational' or zone of ambiguity explanations (Wood, 2002; Golding & Gresty, 2005). Whatever the explanation, the results of the present study suggest that a frequency peak in the 0.2 Hz region may reveal a common causal mechanism of the widely differing stimuli capable of evoking motion sickness.

Nauseogenicity was maximal in the 18^{o}-54^{o} range of tilts and decreased significantly above 54^{o} with a sharp decrease in susceptibility at 72^{o} and 90^{o}. These differences extend the findings of a previous study which showed a significant increase in MS susceptibility as tilt of an optokinetic drum increased from 0^{o} to 10^{o} (Bubka & Bonato, 2003). The stimulus in our study lacked thick black and white lines usually used in previous experiments with optokinetic drums. Such lines may emphasise tilt more strongly than our realistic scene, making them a stronger stimulus. Our scene was complex and contained no solid vertical lines and just one horizontal line which could emphasise tilt, i.e. the horizon. On the other hand an advantage of our stimulus over the standard striped drum is that it can be tilted to any angle between 0^{o} and 90^{o}. Moreover this type of realistic scene may provide more information of relevance to the real world e.g. as in provocative visual view provided by tilting trains (Neimer et al, 2001) and to simulators (Hettinger et al, 1990).

It has been suggested that rotating visual motion at 0^{o} induces MS through vection (Bubka et al, 2003; 2006). In this study the majority of participants spontaneously complained of vection during 0^{o}, 18^{o}, 36^{o}, 45^{o} and 54^{o} conditions, whilst only a few experienced vection at 72^{o} and 90^{o}. Therefore perhaps the only moderate increase in MS susceptibility between 0^{o} and 45^{o} is due to both conditions reliably producing vection and therefore MS, whilst the more extreme angles of 72^{o} and 90^{o} did not. At extreme tilts > 45 degrees it is known that the effect of a tilted visual environment with strong verticals & horizontals, such as in the 'Rod and Frame effect', on perceived verticality begins to decrease. This 'perceptual shift' is thought to be because what were seen as verticals at lower angles of tilt are reassigned horizontal status and vice-versa (Witkin & Asche, 1948ab). However this explanation is perhaps unlikely in our experiment since there were few strong verticals or horizontals. Alternatively, the decrease in MS susceptibility observed at high angles of tilt may be due to the conflict between actual and expected patterns of input becoming so great at extreme tilts, that the mismatch is obvious. As a result the visual input is quarantined by the brain and therefore not utilised in self-motion detection. Put simply, the brain does not believe the visual input. The concept of quarantining of an obviously mismatched visual input was proposed by Gresty and co-authors (2003]. This idea is further supported by the previous observation that very few participants complained of vection at 72^{o} and 90^{o} whilst most experienced vection at 0^{o} , 18^{o}, 36^{o}, 45^{o} and 54^{o}. If the visual input is not being utilised for self-motion detection, then it follows that vection would not occur.

In general, sickness ratings increased with exposure time as usually happens with real motion. However, optokinetic stimuli are weak and a few subjects were able to adapt. After initial increases they showed decreases in sickness ratings towards the end of the ten minute exposure period. This can also occur with real motion stimuli but is rarer. It usually occurs under conditions graded to provide mild provocative stimuli designed to facilitate motion desensitisation, e.g. during desensitisation training of airsick pilots and other aircrew (Golding, 2006b).

This study had a number of limitations. The optokinetic OVAR stimulus was weak compared to real OVAR. Unpublished work in our laboratories shows that optokinetic OVAR at 18 ^{o} tilt at 0.2 Hz is less than half as nauseogenic as the equivalent real OVAR for the same subjects. We did not formally question participants about vection, although many spontaneously reported it. Although this was not a primary aim of our study, this would have been a useful addition to the symptom checklist as the data could be used to check for correlation between vection and MS susceptibility. The lack of order effects shows that there was no habituation to the stimulus, nor were there any carry-over effects from previous conditions, indicating that a recovery time of 10 minutes between conditions was sufficient. However it was necessary to stop at mild nausea in Experiment 3 to reduce the possibility of order or carry-over effects with the higher number of potentially nauseogenic conditions. Although the head was supported during trials and participants were instructed to remain still, the head was not rigidly restrained. Any small movements made could have induced pseudo-coriolis [Eyeson-Annan et al, 1996], though one could assume that this would affect all conditions equally. We were unable to show significant differences in nauseogenicity over the mid range of tilts. This may imply that after the increase from 0^{o} to 18^{o} there is little further increase from 18^{o} up to around 54^{o}, followed by a subsequent decline in nauseogenicity to 90^{o}. However it could be that with more very sensitive subjects and going to higher sickness levels, it may be possible to find a more definite peak in this tilt range. The number of frequency steps was insufficient to determine how close to 0.2 Hz is the exact peak of nauseogenicity. More frequency steps in the range 0.1 to 0.4 Hz might be of interest to define the frequency peak more accurately by comparison with extant data for real motion. Equally, it is possible that the peak frequency could vary with angle of tilt. However this seems unlikely since a 0.2 Hz peak seems invariant across many different types of motions including vertical oscillation, horizontal oscillation and OVAR (see Introduction).

In conclusion the results of this study suggest that the frequency tuning of optokinetic nauseogenicity is similar to that of real motion during OVAR. However, angle of tilt has a different relationship with nauseogenicity for optokinetic OVAR, firstly increasing and then decreasing at very high tilt angles, perhaps due to ‘quarantining’.

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