Seminars on Virtual Reality: selected tools and applications
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CHAPTER X

SCENE MOVEMENT: AN IMPORTANCE CAUSE OF CYBERSICKNESS

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Abstract

Head-coupled (head-steered) virtual reality display systems can cause motion sickness (cyber-sickness). This chapter reviews past literature on cybersickness and reports two series of experiments conducted to identify the cause(s) of cybersickness. The first series consists of two experiments conducted to investigate the effects of and interactions between rotational scene movements and head movement. The aim was to verify the importance of scene movement to the generation of cybersickness. Preliminary results indicate that the presence of scene movement can more than double the level of cybersickness. Initial data also showed that scene movement in the absence of head movement is associated with higher levels of cybersickness than scene movement with either correlated or uncorrelated head movements. The second series of experiments studied the level of cybersickness with scene movements of different complexity and velocity. Significant increases in the level of cybersickness have been obtained when either scene complexity or scene velocity is increased.

X.1 INTRODUCTION

People are used to selecting their viewpoints with head movements. Such ability is inhibited when viewing images presented on a desktop monitor display. With a head-coupled Virtual Reality (VR) display, however, viewpoints of displayed images can be updated according to the viewer's head orientation. A typical head-coupled virtual reality (VR) system consists of a Head Mounted Display (HMD), a head tracker, and a host computer (Figure 1). The HMD presents computer-generated images to an operator and the tracker measures the head position and orientation. When viewing a VR display, the perspective of the images changes according to the viewer's head movement and orientation. McCauley and Sharkey (1992) predicted that when head-coupled VR systems are used to present simulation with rich scene content, the viewer may experience a strong sense of self-motion (vection). According to the sensory conflict theory, this vection can be nausogenic in the absence of appropriate head motion (Reason and Brand, 1975; Griffin, 1990; and Oman, 1993). The motion sickness associated with Virtual Reality systems has been referred to as 'cybersickness' (McCarley and Sharkey, 1992).

Symptoms of motion sickness (e.g., nausea and visual fatigue) have been reported in many studies concerning the use of virtual reality systems. In Europe, Regan and her colleagues have investigated the effects of body posture, adaptation, speed of interactions, exposure duration, and drug treatment on the levels of cybersickness (Regan and Price, 1993a,b,c, 1994). They reported that after a 20-minute simulation with a virtual reality display, 61% of the subjects suffered symptoms of malaise. The symptoms ranged from 'headaches' and 'eyestrain' to 'severe nausea'. A total of 150 subjects were used and 5% of the subjects had to withdraw from the experiment due to 'severe dizziness' (Regan, 1995). Costello and Howarth (1996) reported that when VR games are viewed on an HMD instead of a desktop monitor display, significantly higher symptoms of visual fatigue, sweating, general discomfort, nausea, and disorientation can be produced. In both the Howarth and Regan studies, 'eyestrain' is the most frequently reported symptom (Howarth and Costello, 1997; Regan, 1995). In 1997, Wilson and his colleagues investigated the interactions between the sense of presence and the level of cybersickness. They reported that in one study, reduction in sense of presence was associated with increases in sickness level while in another study, the reverse was found. A possible reason may be due to the difference in the task requirement. Subjects in the latter study required more concentration since it was a VR shooting game rather than a VR navigation tour (Wilson *et al*, 1997). In Germany, Virtual Reality technology has been used in the motor industry for rapid prototyping (Bullinger and Fischer, 1998). It is interesting to observe that there has been no report of cybersickness occurrence with this prototyping application. A possible explanation is that motor prototyping does not require much dynamic scene movement nor body movement. The car designers used the VR display (in this case, the CAVE™) to view the three-dimensional car model in its real size. According to the sensory conflict theory, if there is no scene movement relative to the viewer, there should be no induced vection and, hence, no symptom of motion sickness.

In the United States, research on cybersickness has also been prospering. Kennedy and his colleagues applied decades of research experience in conventional simulator sickness to the study of cybersickness. They developed the Simulator Sickness Questionnaire (SSQ) and methods to analyze and interpret the questionnaire data (Kennedy *et al.*, 1993a, 1994). This SSQ consists of a checklist of 28 sickness symptoms and each symptom is measured by a four-point scale: (0) none; (1) slight; (2) moderate; and (3) severe. Using principle component analyses, three data clusters were identified. They have been referred to as (i) nausea-subscore (NS); (ii) oculomotor subscore (OS); and (iii) disorientation subscore (DS). Each score contains seven sickness symptoms. A total sickness score has also been developed which comprise all the sickness symptoms (in total 16) involved in the three subscores. Details of the SSQ questionnaire and its subscores can be found in Kennedy *et al.* (1993a). This SSQ questionnaire has now been recognized as a standard way to measure cybersickness. The SSQ has been used extensively by Dr. Stanney and her colleagues to identify a sickness profile pattern for Virtual Reality simulation (Kennedy and Stanney, 1997; Stanney and Kennedy, 1998). They reported that cybersickness has a consistent pattern of DS>NS>OS. Similar patterns (DS>NS>OS and DS>OS>NS) have also been reported by Enhrlich and Kolasinski when they studied the influence of subject-related factors on the level of cybersickness (Kolasinski, 1996; Ehrlich, 1997; Ehrlich and Kolasinski, 1998). Kolasinski and her colleagues have successfully modelled the SSQ scores as functions of age, gender, mental rotation ability, and pre-exposure postural stability (Kolasinski and Gilson, 1998). However, Ehrlich (1997) reported that subject variables (age and gender) did not have significant effects on SSQ scores. The recovery times after the occurrence of cybersickness were investigated by Singer and his colleagues (Singer *et al.*, 1998). Results indicated that the SSQ scores will return to the pre-exposure level after a 30-minute recovery time. Singer has also developed a questionnaire to measure sense of presence in a virtual environment (Singer and Witmer, 1995).

In 1994, the author of this chapter reported a cybersickness study in which 29 out of 48 (60%) subjects suffered symptoms of 'general discomfort' after a 20-minute exposure of a VR flight simulation (So, 1994). About 8% of the subjects withdrew from the experiment after reporting 'moderate nausea'. The effects of lags on cybersickness was studied and the results indicated that imposed head movement-related lags up to 280 ms do not significantly increase the nausea ratings. This finding does not agree with that reported by DiZio and Lackner (1997), who found that cybersickness ratings increased with lags. A possible reason for the difference may be with the different types of head movements involved during the two VR simulations. So's study required subjects to oscillate their heads at very low frequencies (0.015 Hz to 0.025 Hz) while subjects in DiZio's study were asked to make rapid head movements once every 5 seconds. Further studies on the interactions between lags and head movements are desirable. Other experimental studies reporting the occurrence of cybersickness include Draper (1988), Rich and Braun (1996), Salzman *et al.* (1995), and Lampton *et al.* (1994). Summaries of the findings from previous studies on cybersickness can be found in Table 1. This table is modified from Lo and So (1999a).

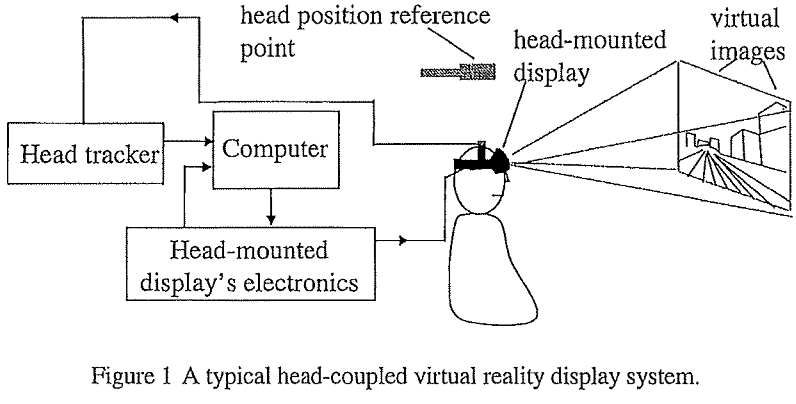

Figure 1 A typical head-coupled virtual reality display system.

Inspection of Table 1 indicates that exposure to a Virtual Reality simulation for 20 minutes or longer will cause symptoms of motion sickness. While different task requirements may result in conflicting findings, scene movements are the common component among all the studies reporting the occurrence of cybersickness. Examples of conflicting results include: effects of subject-related variables: (Kolasinski, 1996 Vs Ehrlich, 1997; and Rich and Braun, 1996); relationship between sense of presence and sickness symptoms (Wilson *et al.*, 1997); and effects of time lags (So, 1994 Vs DiZio and Lackner, 1997). The scene movements experienced by subjects in most studies were either self-generated by subject's head movements or controlled by pre-determined navigation paths. In cases where subjects were using VR displays to view stationary computer generated models, cybersickness problems have not been reported (e.g., Bullinger and Fischer, 1998). This observation is further confirmed by the finding that a higher level of sickness symptoms are reported when a head-steered VR display is used instead of a panel-mounted monitor display (e.g., Howarth and Costello, 1997; Wilson *et al.*, 1997). As predicted by McCarley and Sharkey (1992), cybersickness is a type of visually induced motion sickness (type IIa, Benson, 1984). The visual perception of movements in the absence of any physical movement of the body had been demonstrated to be nauseogenic (e.g., Kennedy *et al.*, 1989). Based on motion sickness studies with fixed-based simulators using panel-mounted displays, Hettinger and Riccio (1992) hypothesized that simulation with head-coupled virtual reality (VR) displays would produce vection-induced motion sickness.

In order to determine the causes of cybersickness, it is essential to understand the effects of visual scene movement. In addition, head movements of an operator may also affect the level of sickness. It is possible to have scene movement (visual stimulus) in contradiction to head movement (vestibular stimulus) -- a type I motion cue mismatch as classified by Benson (1984). All in all, understanding the combined effects of scene movements and head movements is necessary. This chapter presents two series of experiments conducted to study the effects of, and interactions among, scene movement, head movements, and nausea ratings. These studies were funded by the Hong Kong Research Grant Council. The research is still continuing and some initial results are reported in this chapter.

Table 1 Summaries of previous experimental findings on cybersickness (modified from Lo and So, 1999a).

Authors	**Main findings**
Costello and Howarth (1996)	Appreciable changes in heterophoria and visual acuity were reported. However, these changes appeared to be equipment and task dependent. Conditions with VR games viewed on Head-Mounted Displays produced higher symptoms of general discomfort, sweating, nausea, visual fatigue, and disorientation than VR games viewed on a desktop monitor.
Draper (1998)	Levels of SSQ scores increased as the scaling factors between real and virtual dimension deviated from 1.0.
DiZio and Lackner, 1997	Sickness ratings increased with lags. Weight of the HMD did not affect sickness rating. Halving the FOV reduced the sickness rating by half.
Ehrlich (1997)	Subject variables did not have significant effects on SSQ scores. Stereoscopic condition was more nauseogenic than biocular condition. SSQ scores (i.e., nausea, oculomotor, disorientation, and total sickness severity) were significantly correlated with tasks requiring frequent far-near eye fixations. Postural stability measurements were less sensitive than SSQ scores.
Ehrlich and Kolasinski (1998)	Experiment dropouts experienced significantly more nausea than those who finished the experiment. However, there was insufficient evidence to conclude that the two groups differed in terms of total sickness severity scores.
Finch and Howarth (1996)	Conditions with head tracking tasks were more nauseogenic than those with manual tracking tasks without requiring head movement. Sickness ratings increased with increasing exposure duration.
Howarth and Costello (1997)	Conditions with HMD produced higher sickness symptoms than those with desktop monitor. Eyestrain was the most frequently reported symptom.

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.../ Table 1 continued

Lampton *et al.* (1994)	SSQ scores increased after all VR simulation. VR simulation presented through Flight Helmet had similar pattern: Disorientation scores > Oculometor scores > Nausea scores. VR simulations with BOOM display reported higher SSQ scores than those with Flight Helmet, however, the effects of VR displays were confounded with the effects of duration of exposure (duration of BOOM simulation was 80 minutes while durations of those with Flight Helmet were 20 and 40 minutes).
Kolasinski (1996) Kolasinski and Gilson (1998)	Sickness measured as a function of the total severity score from SSQ was successfully modelled as a function of age, gender, mental rotation ability, and pre-exposure postural stability. Females had higher SSQ scores than males although the difference was not significant. Interactions were found between the effects of gender and ability of mental rotation. No evidence for ataxic decrements was found with short exposure (20 minutes) to low-end VR systems.
Regan (1995) Regan and Price (1993b,c)	No significant effect between sitting and standing subjects. Mis-match in IPD can lead to more ocular-related problems.
Regan and Price (1993a, 1994) Regan (1995)	Significant progressions of symptoms with increasing immersion time up to 20 min. Sickness ratings significantly decreased with a repeated immersion within a week. *Hyoscine* (a drug) can reduce nausea and other sickness symptoms.
Rich and Braun (1996)	Sickness symptoms increased with both active control and the use of head tracking. No significant main effects for gender ($p>0.05$).
Salzman *et al.* (1995)	All subjects experienced slight to moderate levels of discomfort and eyestrain after wearing the HMD for approximately 1.25 hours (there were 1 to 2 breaks during the period),
Singer *et al.* (1998)	SSQ scores increased significantly from pre-exposure to mid-experiment measures. SSQ scores obtained at the end of the exposure were not significantly difference from the mid-experiment measures. SSQ scores obtained after 30 minutes of recovery were not significantly difference from the pre-exposure scores.
So (1994)	Nausea ratings increased significantly with exposure duration. An imposed 280ms lag on the conditions with low frequency (0.015 – 0.025Hz) head movements did not increase the nausea ratings. The addition of low frequency yaw head movement (0.015 – 0.025Hz) did not affect the nausea ratings. A subjective rating of simulation realism significantly correlated with symptoms of nausea.
Stanney and Kennedy (1997)	Post-exposure SSQ scores (nausea, oculomotor, disorientation, and total sickness severity scores) were significantly greater than pre-exposure SSQ scores. No significant difference was found between the eyes-open manual pointing performance before and after the VR exposure. Significant difference was found between the eyes-closed pointing performance before and after the VR exposure.
Stanney and Kennedy (1998)	SSQ scores increased with increasing exposure duration although the effects were only significant with disorientation scores. Total sickness scores at 60 minutes after a VR simulation were found to be 10 times higher than the pre-exposure level.
Wilson *et al.* (1997)	Reduction in sense of presence was associated with increases in sickness level.
	The use of HMD resulted in significantly higher ratings on sickness symptom than the use of desktop display. The addition of auditory cues did not affect the sense of presence. There was a positive correlation between the sense of presence and sickness symptom ratings.

X.2 EXPERIMENTS ONE AND TWO: VERIFYING THE CONTRIBUTION OF SCENE MOVEMENT TO CYBERSICKNESS

X.2.1 Experimental details

Two experiments have been performed and the aim was to determine whether or not scene movement is a major cause of cybersickness. Experiment 1 was a within-subject experiment with four conditions and 16 subjects and Experiment 2 was a between-subject experiment with six conditions and 72 subjects. The investigation of the effects of scene movement was only one of the original aims of these experiments. For the purposes of this chapter, data from the relevant conditions were extracted and analyzed and the specific objectives were to (i) compare the levels of cybersickness with and without scene movement; and (ii) to study the effects of different head movements in the presence of scene movements.

Details of Experiment 1 and its full results have been published in Lo and So (1999b). Nausea data obtained with and without scene movement in the yaw axis were analyzed and compared here. For the condition with scene movement, subjects were exposed to a 20-minute Virtual Reality (VR) simulation in which the virtual scene would oscillate in the yaw axis relative to the viewers. The rate of oscillation was 30 degrees per second. For the condition without scene movement, the same virtual environment was presented for 20 minutes but with no scene oscillation. Subjects were asked to keep their heads stationary during both conditions and the order of presenting the conditions was balanced. Nausea ratings were obtained verbally at 5-minute intervals from the start of the VR simulation. The nausea ratings were taken from a seven-point scale used in previous studies: (0) no symptom; (1) any unpleasant symptoms, however slight; (2) mild unpleasant symptom; (3) mild nausea; (4) mild to moderate nausea; (5) moderate nausea but can continue; (6) moderate nausea, want to stop (So, 1994, Woodman and Griffin, 1997). Simulator Sickness Questionnaire (SSQ) data were also collected before and after each simulation exposure. There was at least a seven-day separation between each exposure. A VR4 Head Mounted Display (HMD) and a Silicon Graphics Onyx workstation were used to generate the VR simulation. In Experiment 2, nausea ratings obtained from the following three conditions were analyzed: in the presence of (i) scene movement with no head movement; (ii) scene movement with uncorrelated head movement; and (iii) scene movement with correlated head movement.

Similar apparatus was used in Experiment 2 but the simulation exposure duration was only 10 minutes. During all three conditions, subjects were exposed to scene movement oscillation in the yaw axis at 30 degrees per second. In the condition with uncorrelated head movement, subjects were asked to rotate their heads up and down once every 30 seconds and the speed of rotation was kept to about 30 degrees per second using an audio cue. In the condition with correlated head movement, yaw axis scene movement was self-generated. Subjects were asked to oscillate their heads in the yaw axis at 30 degrees per second. The amplitude of scene movement was about ±60 degrees. Similar to Experiment 1, both nausea ratings and SSQ data were collected. All the subjects were male Chinese. Figure 2 shows a subject wearing the Head Mounted Display.

X.2.2 Results

ANOVAs were performed on the nausea ratings data obtained from 16 subjects in Experiment 1 (16 per condition) and the first 18 subjects in Experiment 2 (six per condition), respectively. Results indicated that exposure duration had significant effects on nausea level in both experiments (Experiment 1: $F_{4,310} = 53.2$, $p<0.001$, Table 2; Experiment 2: $F_{5,90} = 8.9$, $p<0.001$, Table 3). Nausea ratings after the 20-minute Virtual Reality simulation with and without scene movement are illustrated in Figure 3. Mean data of 16 subjects with the standard deviations are shown. It can be observed that the mean nausea level increased threefold in the presence of scene movement. Results of the ANOVA indicate that the effect of scene

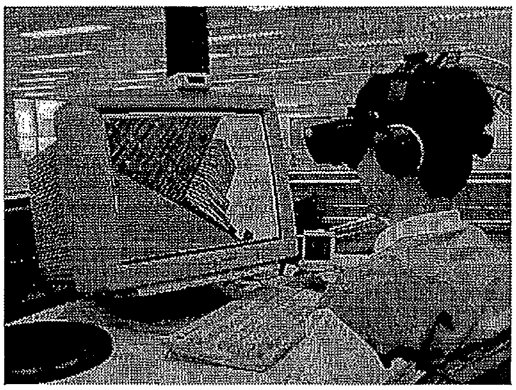

Figure 2 A photo showing a subject wearing the VR4 Head Mounted Display.

movement was very significant ($F_{1,310} = 107.9$, $p<0.0001$, Table 2). Similar effects were also found in the SSQ data and details can be found in Lo and So (1999). Levels of nausea obtained at the end of a 10-minute VR simulation with scene movement and three types of head movements are illustrated in Figure 4. The three types of head movements are (i) head movement uncorrelated with scene movement; (ii) no head movement; and (iii) head movement correlated with scene movement. It can be observed that scene movement in the absence of head movement will produce higher sickness than in the presence of either correlated or uncorrelated head movement. Results of the ANOVA show that head movement has a significant effect ($F_{2,90} = 3.1$, $p<0.05$). Post-hoc analyses using SNK confirm the observation that the condition without head movement has a significantly higher nausea rating ($p<0.05$) while no significant difference can be found between the nausea rating obtained with correlated and uncorrelated head movement.

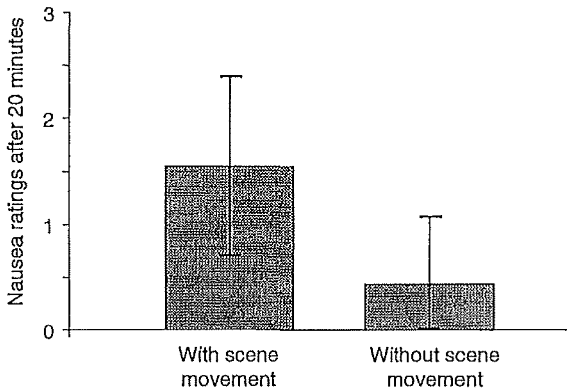

Figure 3 Nausea ratings after 20 minutes exposure to VR simulation with and without scene movement (mean data of 16 subjects with ± one standard deviation, modified from Lo and So, 1999b).

Table 2 ANOVA performed on nausea ratings obtained in Experiment 1 to study the effects of scene movement (with / without) and exposure duration (0, 5, 10, 15, 20 minutes). Data from 16 subjects (modified from Lo and So, 1999b).

Dependent Variable: Nausea ratings

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Scene movement (with/without)	1	34.13	34.13	107.88	0.0001
Duration	4	67.34	16.84	53.22	0.0001
Scene*Duration	4	9.89	2.47	7.82	0.0001
Error	310	98.06	0.32		
Corrected Total	319	209.42			

Table 3 ANOVA performed on nausea ratings obtained in Experiment 2 to study the effects of head movements (no head movement, correlated head movement, uncorreletaed head movement) and exposure duration (0, 2, 4, 6, 8, 10 minutes). Data from 18 subjects.

Dependent Variable: Nausea ratings

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Head movement	2	2.89	1.44	3.11	0.0495
Duration	5	20.64	4.13	8.88	0.0001
Head*Duration	10	2.89	0.29	0.62	0.7919
Error	90	41.83	0.47		
Corrected Total	107	68.25			

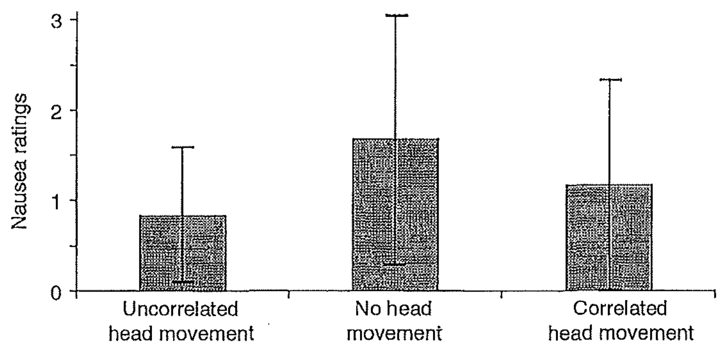

Figure 4 Nausea ratings after a 10-minute exposure to VR simulation with yaw axis scene movement and different types of head movements (mean data of 6 subjects with ± one standard deviation).

X.3 EXPERIMENTS THREE AND FOUR: CYBERSICKNESS WITH DIFFERENT LEVELS OF SCENE MOVEMENTS

X.3.1 Experimental details

Experiment 1 has confirmed that the prediction of scene movement in a VR simulation can significantly increase the level of nausea. Two more experiments were conducted to further study the effects of scene movement by varying the movement velocity and scene complexity. Experiment 3 used three levels of scene velocity and Experiment 4 used two levels of scene complexity. Sixty male Chinese subjects participated in the two experiments (i.e., 12 subjects per condition). The apparatus used was the same as those used in Experiments 1 and 2 although a different virtual environment was presented to the subjects. Subjects were exposed to a 30-minute navigation tour of a virtual city and the dominant scene movements relative to the viewers were in the fore-and-aft and yaw direction. The tour also included occasional pitching movements. The r.m.s. scene velocities in the fore-and-aft axis for the three velocity conditions in Experiment 3 were: 3.4 m/s (v0); 4.4 m/s (v1); and 9.6 m/s (v2). In Experiment 4, a velocity of 9.6 m/s was used in both scene complexity conditions. The scene complexity was quantified using average 'radial spatial frequency' in cycles of image contrast per degree (cpd). Details of the use of spatial frequencies to quantify scene complexity in a virtual environment has been reported in Lo and So (1999a). The virtual scenes used in the two scene complexity conditions had the following average radial spatial frequencies: low - 0.003 cpd; high - 0.2 cpd. Similar to Experiments 1 and 2, both nausea ratings and the SSQ data were collected.

X.3.2 Results

Nausea rating data obtained from the first 18 subjects (Experiment 3) and the first 12 subjects (Experiment 4) are presented here. Data analyses are continuing and the complete results will be published when the analyses are completed. Nausea ratings after 30 minutes of VR simulation with different scene velocities are illustrated in Figure 5. As shown in the figure, the nausea rating increased with increasing velocities and the effect was very significant (ANOVA: $F_{2,105} = 19.5$, $p<0.0001$, Table 4). Increase in scene complexity also significantly increased nausea ratings (Figure 6, ANOVA: $F_{1,70} = 51$, $p<0.0001$, Table 5). Similar to Experiments one and two, exposure duration has a very significant effect on nausea levels ($p<0.0001$, Tables 4 and 5).

Table 4 ANOVA performed on nausea ratings obtained in Experiment 3 to study the effects of scene movement velocity and exposure duration (0, 5, 10, 15, 20, 25, 30 minutes). Data from 18 subjects.

Dependent Variable: Nausea ratings

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Scene velocity	2	72.21	36.10	19.47	0.0001
Duration	6	112.89	18.81	10.15	0.0001
Scene*Duration	12	25.35	2.11	1.14	0.0001
Error	105	194.67	1.85		
Corrected Total	125	405.11			

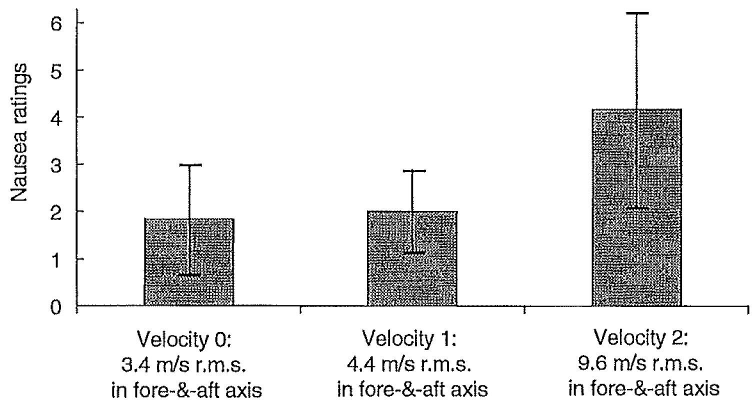

Figure 5 Nausea ratings after a 30-minute exposure to VR simulation with scene movements of different velocities (mean data of 6 subjects with ± one standard deviation).

Table 5 ANOVA performed on nausea ratings obtained in Experiment 4 to study the effects of scene complexity and exposure duration (0, 5, 10, 15, 20, 25, 30 minutes). Data from 12 subjects.

Dependent Variable: Nausea ratings

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Scene complexity	1	107.44	107.44	50.00	0.0001
Duration	6	64.14	16.69	5.07	0.0002
Head*Duration	6	36.48	6.08	2.89	0.0143
Error	70	147.50	2.11		
Corrected Total	83	355.56			

X.4 DISCUSSIONS

The presence of scene movement has been shown to significantly increase nausea ratings from 'no symptom' to 'mild nausea' (p<0.001, Table 2). In the absence of scene movement, more than half of the subjects reported 'no symptom' at the end of a 20-minute Virtual Reality (VR) simulation. None of the subjects suffered from 'mild' or more severe 'nausea symptom'. This suggests that scene movement is essential for the generation of cybersickness. This finding is consistent with the sensory conflict theory which predicts that scene movement in the absence of appropriate head movement will cause vection-induced motion sickness. Subjects in the experiment investigating the effect of scene movement were asked to keep their heads stationary. In order to verify the prediction from sensory conflict theory, Experiment 2 was conducted. The effects of different head movements in the presence of scene movement were studied. Results showed that types of head movements can significantly affect levels of nausea after a VR simulation ($p<0.05$, Table 3). Among the three types of head movements (i.e., no head movement, head movement correlated with scene movement; and head movement not correlated with scene movement), the highest nausea ratings were obtained when scene movement was presented without any head movement. No significant difference was found between the nausea data obtained with correlated and uncorrelated head movements. The former finding that scene movement in the absence of head movement will produce high levels of sickness ratings is consistent with the sensory conflict theory. However, according to the theory, correlation between the scene and head movements should reduce the level of sickness ratings. This was not found to be the case. Possible explanations include the image update lags and the weight of the Head Mounted Display (HMD). The lag of the VR system was measured and the average image update lag in response to a head movement was about 67 ms. Since conflicting results on the effects of lags on cybersickness have been reported (So, 1994; DiZio and Lackner, 1997), further studies are needed to confirm the influence of lag on the nausea levels. The weight of the HMD was measured as 0.95 kg. It is possible that symptoms of fatigue were generated when the subjects were asked to oscillate their heads while wearing the 0.95 kg HMD. Again, further study is needed to confirm this. Since the presence of scene movement could cause significant increases in the level of nausea, its effects were further studied in two experiments (Experiments 3 and 4). Nausea ratings were found to increase with either increasing scene velocity or scene complexity ($p<0.05$, Tables 4 and 5). This confirms that scene movement is an important cause of cybersickness. If scene movement can be quantified, it could be used to predict the level of nausea associated with a VR system. Kennedy *et al.* (1993b) reports the first attempt to quantify the scene movement for this purpose. However, the quantifying procedure was labour intensive and time consuming. In 1999, the authors reported a method to quantify scene movement using a metric called 'spatial velocity (SV)'. This SV metric can be calculated using a MATLab batch file. SV has been shown to have significant effect on both the level of nausea and the SSQ Total Sickness Scores (So and Lo, 1999a; Lo *et al.*, 1999).

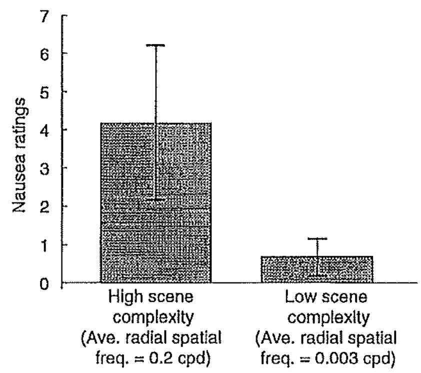

Figure 6 Nausea ratings after 30 minutes exposure to VR simulation with different levels of scene complexity (mean data of 6 subjects with ± one standard deviation).

X.5 CONCLUSION AND RECOMMENDATIONS

Sensory conflict theory predicts, and this study verifies, that viewing virtual scene movement in the absence of physical movement is nausogenic. As exposure duration increases, the level of nausea also increases. Without scene movement, exposure to a 20-minute Virtual Reality simulation did not result in nausea symptom.

When scene movement is changed by increasing movement velocity, the level of nausea will increase significantly. A similar pattern is found when scene movement is changed by increasing scene complexity.

Virtual scene movement in the presence of uncorrelated head movement has been shown to significantly increase the level of nausea rating. To the contrary of the sensory conflict theory, viewing scene movement generated from, and correlated with, head movements also increases the level of cybersickness. Possible explanations have been provided and further studies are desirable.

Experimental results have consistently shown that scene movement is an important cause of cybersickness. It can, therefore, be concluded that scene movement can be used to predict levels of cybersickness. A method to quantify scene movement in a virtual simulation is needed.

Some of the results shown here are preliminary data from the experiments. Data analyses are continuing and the full results will be published once they are ready.

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REFERENCES

Benson, A.J. (1984) Motion sickness. In: Vertigo (Dix, M.R. and Hood, J.S., eds, Chap. 19, pp. 391-426. New York: Wiley.

Bullinger, H.J. and Fischer, D. (1998) New concepts for the development of innovative products – digital prototyping. Plenary paper. Proceedings of the third annual International Conference on Industrial Engineering Theories, Applications and Practice. 28-31, December, Hong Kong.

Crowley, J.S. (1987) Simulator sickness: a problem for army aviation. Aviation, Space and Environmental Medicine 58: pp. 355-357.

Costello, P.J. and Howarth, P.A. (1996) The visual effects of immersion in four virtual environments. VISERG Internal Report 9604. Department of Human Sciences, Loughborough University, Leicestershire, LE11 3TU, United Kingdom.

DiZio, P. and Lackner, J.R. (1997) Circumventing side effects of immersive virtual environments. Proceeding of the 7th International Conference on Human-Computer Interaction, 24-29 August, San Francisco, CA.

Ehrlich, J.A (1997) Simulator sickness and HMD configuartion. Proceedings of SPIE conference on Telemanipulator & Telepresence Technology, SPIE Vol. 3206, pp. 170-178.

Ehrlich, J.A. and Kolasinski, E.M. (1998) A comparison of sickness symptoms between dropout and finishing participants in virtual environment studies. Proceedings of the Human Factors and Ergonomics Society 42nd annual meeting, Chicago, USA, 5-9 September, pp. 1466 – 1470.

Griffin, M.J. (1990) Physical characteristics of stimuli provoking motion sickness. Paper 3 in: Motion Sickness: Significance in Aerospace Operations and Prophylaxis. AGARD Lecture Series LS-175, ISBN 92-835-0634-0.

Finch, M. and Howarth, P.A. (1996) A comparison between two methods of controling movement within a virtual environment. VISERG Internal report 9606. Department of Human Sciences, Loughborough University, Leicestershire, LE11 3TU, United Kingdom.

Hettinger, L.J. and Riccio, G.E. (1992) Visually-induced motion sickness in virtual environment. *Presence*, Vol. 1, No. 3, pp. 306-310.

Howarth, P.A. and Costello, P.J. (1997) The occurrence of virtual simulation sickness symptoms when an HMD was used as a personal viewing system. Display, vol.18, no.2, pp. 107-116.

Kennedy, R.S. and Stanney, K.M. (1997) Aftereffects of virtual environment exposure: psychometric issues. Proceeding of the 7th International Conference on Human-Computer Interaction, 24-29 August, San Francisco, CA.

Kennedy, R.S., Lilienthal, M.G., Berbaum, K.S., Baltzley, B.A. and McCauley, M.E. (1989) Simulator sickness in U.S. Navy flight simulators. *Aviation, Space and Environmental Medicine*, **60**, No.1, pp. 10-16.

Kennedy, R.S., Berhaum, K.S. and Smith, M.G. (1993a) Methods for correlating visual scene elements with simulator sickness incidence. Proceedings of the Human Factors and Ergonomics Socity 37th Annual Conference, pp.1252-1256.

Kennedy, R.S., Lane, N.E., Berbaum, K.S. and Lilienthal, M.G. (1993b) Simulator Sickness Questionnaire (SSQ): a new method for quantifying simulator sickness. International Journal of Aviation Psychology, 3(3), pp. 203-320.

Kennedy, R.S., Drexler, J.M. and Berbaum, K.S. (1994) Methodological and measurement issues for identification of engineering features contributing to virtual reality sickness. Proceedings of the IMAGE VII Conference, Tucson, Arizona 12-17 June 1994.

Kolasinski, E.M. and Gilson, R.D. (1998) Simulator sickness and related findings in a virtual environment. Proceedings of the Human Factors and Ergonomics Society 42nd annual meeting, Chicago, USA, 5-9, October, pp. 1511-1515.

Lampton, D.R., Kolasinski, E.M., Knerr, B.W., Bliss, J.P., Bailey, J.H. and Witmer, B.G. (1994) Side effects and aftereffects of immersion in virtual environments. Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting. Santa Monica, CA: Human Factors & Ergonomics Society. pp. 1154-1157.

Lo, W.T. and So, R.H.Y. (1999a) Use of 'spatial velocity' to quantify virtual scene movement for the study of cybersickness. Submitted to PRESENCE.

Lo, W.T. and So, R.H.Y. (1999b) Effects of scene rotational movements on levels of cybersickness. Submitted to Applied Ergonomics.

Lo, W.T., So, R.H.Y., and Ho, A.T.K (1999) 'Spatial Velocity' as a predictor variable for levels of cybersickness. Awaiting publication.

McCauley, M.E. and Sharkey, T.J. (1992) Cyber-sickness: perception of self-motion in virtual environments. *Presence*, Vol. 1, No. 3, pp. 311-317.

Oman, C.M. (1993) Sensory conflict in motion sickness: an observer theory approach. Chapter 24 in: Pictorial communication in virtual and real environments. Editor: Ellis, S.R., Taylor & Francis, pp. 362 - 375.

Reason, J.T. and Band, J.J. (1975) Motion sickness. Academic Press, London, ISBN 0-12-584050-0.

Regan, E.C. (1995) An investigation into nausea and other side-effects of head-coupled immersive virtual reality. *Virtual Reality: research, development and applications.* Vol. 1, No. 1, pp. 17-32.

Regan, E.C. and Price, K.R. (1993a) Some side-effects of immersion virtual reality. APRE, United Kingdom MOD. Report 93RO10.

Regan, E.C. and Price, K.R. (1993b) Subjective views on an immersion virtual reality system and its peripherals. Working paper 16/93, United Kingdom MOD.

Regan, E.C. and Price, K.R. (1993c)Some side-effects of immersion virtual reality: the effects of increasing head movements, rapid interaction, and seating subjects. APRE, United Kingdom MOD, Report 93RO22.

Regan, E.C. and Price, K.R. (1994) The Frequency of Occurrence and Severity of Side-Effects of Immersive Virtual-Reality. Aviation, Space, and Environmental Medicine. Vol. 65, No. 6, pp. 527-530.

Rich, C.J. and Braun, C.C. (1996) Assessing the impact of control and sensory compatibility on sickness in virtual environments. Proceedings of Human Factors and Ergonomics Society 40th Annual Meeting, Santa Monica, CA: Human Factors & Ergonomics Society. pp. 1122-1125.

Salzman, M.C., Dede, C. and Loftin, R.B. (1995) Usability and learning in educational virtual realities. Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, Santa Monica, CA, pp. 486-490.

Singer, M.J. and Witmer, B.G. (1995) Presence measure for virtual environments: background and scoring instructions. Working paper from US Army Research Institute, 1995.

So, R.H.Y (1994) An investigation of the effects of lags on motion sickness with a head-coupled visual display. Proceeding of the United Kingdom Informal Group Meeting on Human Response to Vibration held at the Institute of Naval Medicine, Alverstoke, Gosport, Hants, PO12 2DL. 19 – 21, September.

Stanney, K.M. and Kennedy, R.S. (1998) Aftereffects from virtual environment exposure: how long do they last? Proceedings of the Human Factors and Ergonomics Society 42nd annual meeting, Chicago, USA, 5-9, October, pp. 1476-1480.

Wilson, J.R., Nichols, S. and Haldane, C. (1997) Presence and side effects: complementary or contradictory? Proceedings of the 7th International Conference on Human-Computer Interaction, San Francisco, August, pp. 889-892.

Woodman, P.D. and Griffin, M.J. (1997) Effects of direction of head movement on motion sickness caused by coriolis stimulation. Aviation, Space & Environmental Medicine, Vol. 68, pp 93-98.