Effects of Eye Movement on Visually Induced Motion Sickness

by

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in Partial Fulfillment of the Requirements for

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the thesis examination committee have been made.

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Table of content

List of figures

List of tables

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Abstract

Eye movement has been considered as an important factor to influence the Visually Induced Motion Sickness (VIMS). Two experiments were conducted in this thesis. The first experiment focused on the presence of eye movements (i.e., with and without eye fixation). Factorial combinations of two speed levels of visual motion and two levels of eye fixation (with and without) were examined. Result showed that the presence of the eye movement significantly increased the levels of VIMS ($p<0.005$). Also, the speed of the visual motion had a significant effect on the levels of VIMS ($p<0.005$). Visual stimuli rotating at 61.5 degree per second (dps) evoked larger levels of VIMS than at 6.8 dps. The interactions between the effects of eye movements and the effects of visual motion speed are discussed. The second experiment was a following up study on two properties associated with eye fixation: (i) zero foveal retinal slip velocity and (ii) zero eye movement velocity. Three conditions were studied: (i) both foveal retinal slip velocity and eye movement velocity were zero; (ii) zero foveal retinal slip velocity with eyes following a marker moving at 34 dps; and (iii) both foveal slip velocity and eye movement velocity were non-zero and following pattern rotating at 34 dps. Result showed that changing the velocity of the eye movement significantly affected the evoked VIMS ($p<0.05$), while changing the velocity of the foveal retinal slip did not significantly affect levels of VIMS ($p>0.05$). Thus the zero eye movement velocity rather than zero foveal slip velocity is considered to be a key factor in reducing levels of VIMS.

Chapter 1. Introduction to motion sickness and related theories

1.1 Motion sickness and Visually Induced Motion Sickness (VIMS)

Motion sickness is the discomfort one may have when exposed to a conflict generated by visually perceived movement and vestibular system's sense of movement. The visually perceived movement is the movement received by people's eyes; the vestibular system is the "inner ear organs provide us with our subjective sense of movement and orientation in space" (Cullen, K and Sadeghi, S, 2008). A simple example of motion sickness would be someone standing at the bottom of a ship. As she/he is standing still, the visually perceived movement for the person would be stationary, while the vestibular system can feel the ship is swaying in the sea. Hence there is a conflict generated by the two feelings. And it would be very possible for this person to feel motion sickness, even start to vomit.

There are different kinds of motion sickness. Depending on which feeling is the dominating one in generating the conflict, they can be divided into two groups: vestibular motion dominating motion sickness and visual motion dominating motion sickness. Vestibular motion dominating motion sickness includes sea sickness, car sickness, air sickness and space sickness. As can be found from the names, most of them just happen in the situations with transportation tools. Visual motion dominating motion sickness includes the visually induced motion sickness (VIMS), which is the main research target in this thesis.

VIMS is often caused by the presence of visual perceived movement in the absence of appropriate vestibular perceived movement. The main differences between VIMS and other kinds of motion sickness come from the generated symptoms. Kennedy et al in 1992 summarized the main symptoms of VIMS and developed a Simulator Sickness Questionnaire (SSQ). They believed that symptoms like pallor, sweating, salivation, nausea, drowsiness, general discomfort, apathy, headache, stomach awareness, disorientation, fatigue, and incapacitation are the main symptoms in VIMS. Unlike other motion sickness, vomit and retching are rare in the VIMS and ocular related symptoms happen more frequently (Kennedy, 1992). Such a questionnaire focuses on those symptoms had been wildly used in VIMS related researches and was also used in this thesis' experiments to study the levels of discomfort of the subjects.

Due to the increase in the access of video/computer games, movies, videos and pictures in daily life, the study of VIMS is being paid more and more attention to in these years. The International Workshop Agreement 3 of ISO (International Organization for Standardization) was an agreement especially on the field of image safety (ISO, 2005). The purpose of this agreement was to "establish the concept of image safety for all categories of image providers as well as for those who view moving images, such as computer/video games, movies, videos and video pictures on websites. It also defines the following undesirable biomedical effects caused by moving images: photosensitive seizures; visually-induced motion sickness; visual fatigue." The Commission Internationale de L'Eclairage (CIE) also set a Technical Committee to focus on the topic of "The Effects of Dynamic and Stereo Visual Images on Human Health", which also listed VIMS as an important research field in it (CIE, TC 1-67, 2006).

1.2 Related theories to motion sickness

1.2.1 Sensory conflict theory

One modern explanation to the motion sickness is the sensory conflict theory (Reason, 1975). Such theory came from Reason's sensory rearrangement theory published in 1975. By this theory, Reason wanted to summarize the common characteristic of all the kinds of motion sickness. He believed all the situations that can evoke motion sickness contain a conflict among the motion signals transmitted by the eyes, vestibular system and non-vestibular proprioceptors. The motion feelings of those organs don't show a consistency with the history in the motion sickness' cases. And Reason defined motion sickness as "a self-inflicted maladaptation phenomenon that occurs at the onset and cessation of conditions of sensory rearrangement when the prevailing inputs from the visual and vestibular systems are at variance with stored patterns derived from previous transactions with the spatial environment". This theory is wildly accepted by the research field now and it is also used to give the explanation to motion sickness.

1.2.2 Other related theories

Although sensory conflict theory is accepted by a lot of people now, it wasn't how motion sickness was understood in the beginning. The studies of motion sickness focused on clinical evidence in the early stages. Acceleration-induced cerebral ischemia was considered to be responsible for the motion sickness one century ago. But later the inner ear vestibular organs' function in body movement control was found. Theories related to such vestibular organs became largely supported and had replaced the cerebral ischemia theory since then. Key evidence for such changes came from James, who found that people lack vestibular functions appeared to be immune to the motion sickness (James, 1882).

Besides the inner ear organs, the eye muscle afference is also considered to be an important factor to influence the motion sickness. As the clinical cases on the strabismus surgeries showed that, in the 24 hours postoperative period of the surgery, people who were given a supplementary local retrobulbar anesthesia during the operation experienced less emesis and nausea than those who weren't given such anesthesia. The function of such anesthesia is to block the afferent signals emanated from stretched extraocular muscle (Houchin et al, 1992). Hence it is believed that such ocular muscle afference played an important role in evoking motion sickness. Ebenholtz in 1994 brought out a hypothesis that different kinds of eye movements may evoke different levels of motion sickness, as they should evoke different dose of eye muscle afference (Ebenholtz, 1994).

Those theories would be detailed explained later in the motivation part of the experiments if they are related to the studies in this thesis.

Chapter 2. Apparatus, screening tests and methodologies in the experiments

2.1 Apparatus in the experiments

The apparatus in the experiments included a screen and 3 projectors which were used to generate the visual stimuli; a body movement tracking system (Polhemus system) which was used to collect the body movement data; an eye muscle movement tracking system (EOG system) which was used to collect the eye movement data; a video recorder which was used to record the video for the whole experiments; a chin rest which was used for the subjects to maintain steady head posture in the experiments. A picture of how some of those apparatus were located in the experiments can be found in figure 2.1.

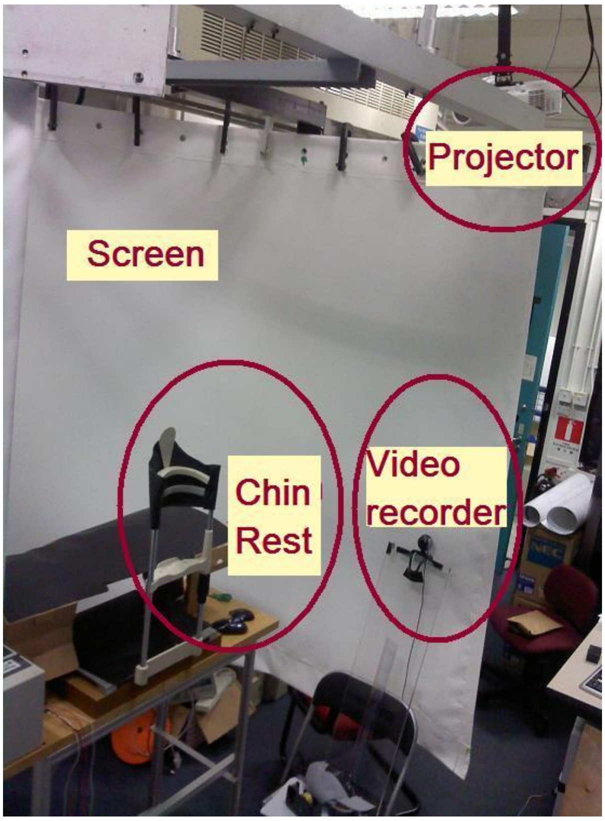

Figure 2.1 An overview picture of the experiment environment

2.1.1 Visual stimuli generator (Screen and Projectors)

The visual stimuli in the experiments were generated by a VB program in the PC. The properties of the PC are listed in table 2.1.

System:	Microsoft Windows XP Professional Version 2002 Service Pack 2
Computer:	Inter(R) Corel(TM)2 Duo CPU E6750 @ 2.66G Hz
RAM:	2.67G Hz, 3.25G Hz of RAM
Graphic Card:	NVIDIA GeForce 8800 GTS 512

Table 2.1 Properties of the PC used for generating the visual stimuli in the experiments

After the images of the visual motion were generated, they were projected to a semi-cylinder screen by 3 projectors, with the update rate of 60 Hz. The resolution of the images projected to the screen was 1920X480 pixels. The properties of a single projector are listed in table 2.2.

Title:	NEC Projector LT 380G
Lightweight:	3.5 kg
High brightness:	3000 ANSI lumens
Resolution:	XGA (1024 x 768 dots)

Table 2.2 Properties of the projector used for generating the visual stimuli in the experiments

2.1.2 Polhemus body movement tracking system

The “Polhemus 3space” system was used to record the body movement in the experiments. It can record the movement of a sensor in the space with 6 degrees of freedom. The properties (accuracy, latency and so on) of the Polhemus apparatus are listed in table 2.3 and the definition of the x, y, z axis can be found in figure 2.2.

Degrees-of-Freedom:	6DOF (3 positions: X, Y, and Z Cartesian coordinates and 3 orientations: azimuth, elevation, and roll)
Number of Sensors:	1-4
Update Rate:	80 Hz (divided by number of sensors)
Static Accuracy Position:	0.0015 inch
Static Accuracy Orientation:	0.15 RMS
Latency:	4ms
Resolution Position at 30cm range:	Resolution Position per inch of source and sensor separation
Resolution Orientation:	0.025
Range from Standard TX2 Source:	Up to 5 feet or 1.52 meters
Extended Range Source:	Up to 15 feet or 4.6 meters
Interface:	RS-232 or USB (both included)
Host OS compatibility:	GUI/API Toolkit 2000/XP

Table 2.3 Properties of the Polhemus system used in the experiments

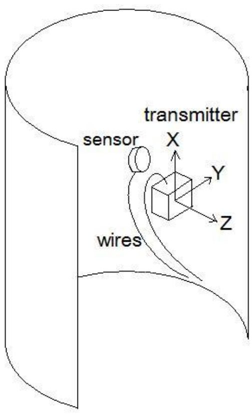

Figure 2.2 The definitions of x, y and z axis in the experiments

The components of the Polhemus include a sensor and a transmitter. They are shown in figure 2.3 and figure 2.4:

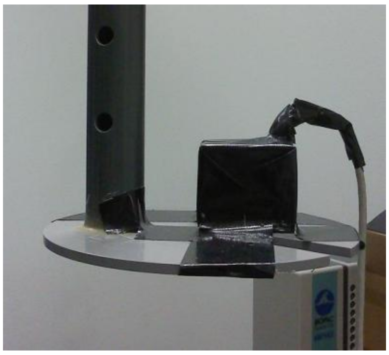

Figure 2.3 The transmitter of the Polhemus

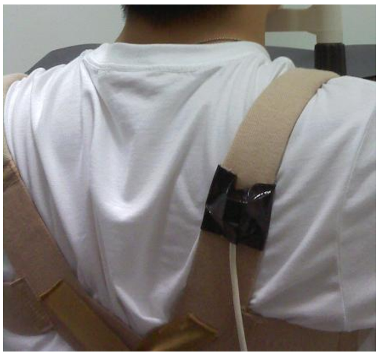

Figure 2.4 The sensor of the Polhemus

As can be seen from figure 2.3 and figure 2.4, the transmitter was put on a plastic plate that was hung from a wooden frame, and it was put approximately 20~30 cm away from the sensor in the experiments. The sensor was attached on a belt. During the experiments, the subjects were requested to wear the belt with the sensor located on their back.

Each time before the experiment started, the subjects were required to perform the posture that they were supposed to hold during the whole experiment, as can be found in figure 2.5. Then the status of the Polhemus was "re-initialized to the power up state" by using the function of the Polhemus apparatus. It also was boresighted to make the 3 orientation angles reset to zero. Then the Polhemus started to record the body movement data from the time the subjects were told to open their eyes until the experiment was finished.

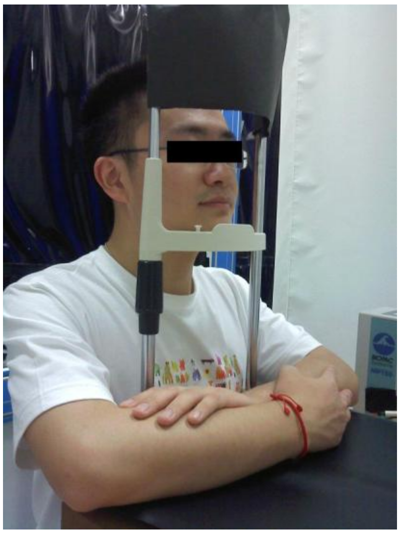

Figure 2.5 The posture for the subjects to hold during the experiments

In the Polhemus record, a typical series of Polhemus data are shown in table 2.4. The unit for the 3 axis is CM, for the 3 angles is degree.

port	x_axis	y_axis	z_axis	azimuth	elevation	roll
1	1.37	-7.85	-32.39	-0.05	0.24	0.27
1	1.37	-7.86	-32.38	-0.05	0.23	0.26
1	1.37	-7.85	-32.39	-0.04	0.24	0.28
1	1.37	-7.86	-32.39	-0.04	0.25	0.26
1	1.37	-7.85	-32.39	-0.05	0.27	0.27
1	1.38	-7.85	-32.39	-0.05	0.27	0.26

Table 2.4 A typical series of Polhemus data in the experiments

After the data was recorded, the SAS software was used to obtain the standard deviation of the data, especially in the x, y and z directions. The data of those standard deviations were used to prove that the subjects didn't experience large vibrations during the whole experiment.

2.1.3 The EOG (Electrooculography) apparatus for eye movement

The EOG equipment (MP150 STARTER SYSTEM) was used to record the eye movements in the experiment. Properties of the EOG equipment can be found in table 2.5.

Analog Inputs	
Number of Channels:	16
Input Voltage Range:	±10V
A/D Resolution:	16 Bits
Accuracy (% of FSR):	±0.003
Input impedance:	1.0 MW

Analog Outputs	
Number of Channels:	2
Output Voltage Range:	±10V
D/A Resolution:	16 bits
Accuracy (% of FSR):	±0.003
Output Drive Current:	±5mA (max)
Output Impedance:	100W
Digital I/O	
Number of Channels:	16
Voltage Levels:	TTL, CMOS
Output Drive Current:	±20mA (max)
External Trigger Input:	TTL, CMOS compatible
Time Base	
Min Sample Rate:	2 samples/hour
Trigger Options:	Internal, External or Signal Level
Power	
Amplifier Module Isolation:	Provided by the MP unit
CE Marking:	EC Low Voltage and EMC Directives
Leakage current:	<8µA (Normal), <400µA (Single Fault)
Fuse:	2A (fast blow)

Table 2.5 Properties of the EOG apparatus

Before the experiments began, 5 electrodes were placed on the face of each subject. One was put on the forehead, two were put on the temples and two were put on the upper and lower side of their dominant eyes. An illustration of how the electrodes were located on the face can be found in figure 2.6. The one on the forehead was used for the ground signal. The two on the temples were used to test the horizontal eye movements of the subject. The two on the upper and lower side of the dominant eye were used to test the vertical eye movements of the subjects. The vertical movement data was used to prove that the subjects didn't have significant up and down eye movements, while the horizontal movement data was used to record the horizontal eye movements of the subject.

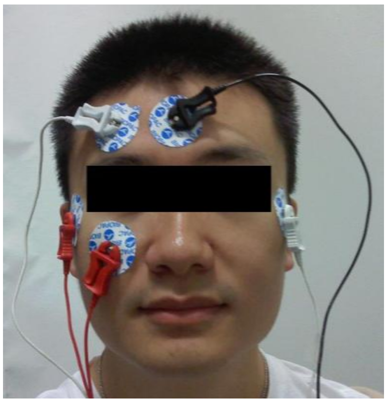

Figure 2.6 An illustration of how the 5 electrodes were located on the subject's face

The signal received from the EOG was the volt signal representing the movements of the eye muscle activities. So there should be a procedure to convert the data of muscle activity into data representing where the subjects looked at.

Each time after the electrodes were put on the subjects' faces, they participated in a mapping test for the EOG. Two dots with a distance of 15 degrees' visual angles were shown to the subjects. The two dots showed up alternately. Each dot appeared for 5 seconds, and then another one immediately showed up after this one disappeared. The purpose of such mapping test was to get a mapping relationship on how much visual angle it represented if the output of the EOG signal changed for 1 volt. A typical EOG pattern for the mapping test is shown in figure 2.7. The two big changes in the EOG pattern represent the time when the subjects focused their eyes from one dot onto another. From this figure, it can be calculated that if the EOG input changes for 1 volt, how many degrees it represented for the eye movement.

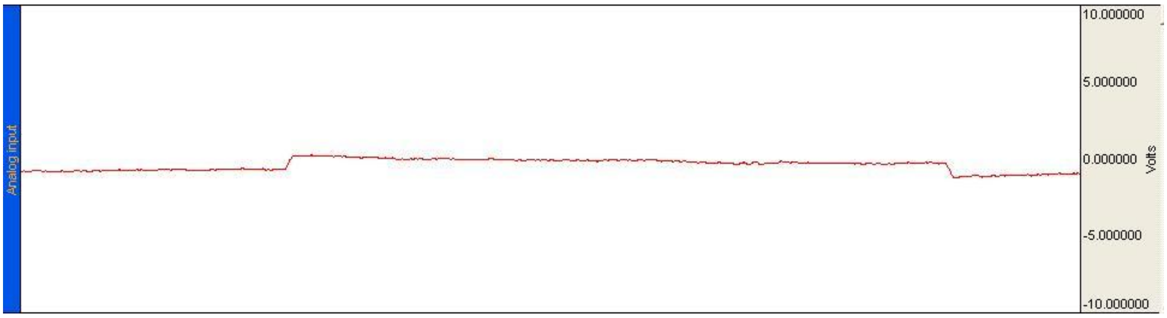

Figure 2.7 A typical EOG pattern got in the mapping test

The eye movement in the EOG data can be grouped into two phases, one is slow phase and the other is fast phase. For a typical OKN (optokinetic nystagmus) eye movement cycle, it should have a slow phase first which indicates, especially in the experiments, the subjects' eyes are moving with the visual stimuli. Then there would be a fast phase which indicates there is a saccade in the eye movement. As shown in figure 2.8, which is an ideal EOG recorded eye movement pattern, the EOG pattern between the two color lines indicates a typical OKN cycle, the up-going part is the slow phase while the down-going part is the fast phase. The vertical amplitude of the OKN cycle means how far the subjects' eyes go for one cycle. The slot of the slow phase is converted into the speed of the eye movement by the mapping constant got from the mapping test.

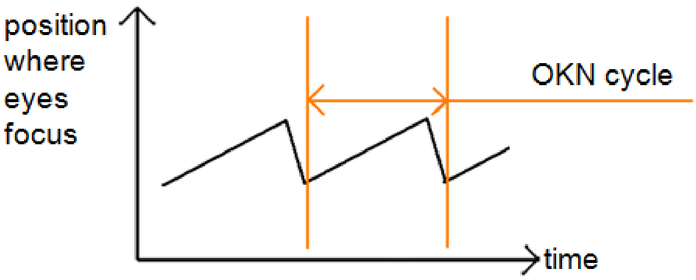

Figure 2.8 An ideal EOG pattern

When the experiments start, the EOG would begin to collect the eye movement data. The average slow phase velocity (SPV) and the average amplitude for the OKN cycle would be calculated based on the data and the result of the mapping tests.

2.1.4 Video recorder

All the experiments were completed with video records. The webcam used for recording the experiments was a Logitech QuickCam S5500, with a true 1.3-megapixel sensor, RightLight™ technology, RightSound™ technology, and Logitech® Fun Filters.

The webcam was placed at one side of the subject as shown in figure 2.1. Each time before the experiment started, the subjects were asked whether they thought the webcam affected their eye sight or not. The position of the webcam was adjusted so that it wouldn't affect their eye sight. Also the webcam was adjusted to mainly record the head movements of the subjects so that the record can be the evidence that the subjects didn't have very large head movements during the experiments.

2.2 Screening tests in the experiments

Two tests were used in the experiments to screen out some inappropriate subjects. One was the eyesight test; the other was the line length estimation test.

2.2.1 Eyesight test

The subjects' eyesight was tested by using the vision tester model 2000 produced by the Stero Optical Corporation. The subjects' eyesight of the both eyes and single eyes were all tested, using the conditions of long and short sightedness (in the conditions of far scene and near scene.) To pass the eyesight screen test, the subjects needed to get a visual score better than 20/22 in the Snellen 20/20 Visual Acuity scale for both eyes in both conditions. The scores for their single eyes weren't used to screen out any subjects but kept for the record.

During the eyesight test, the subjects were shown a picture like figure 2.9 through the vision tester. Figure 2.9 shows the images when the subjects were tested for their right eyesight (if they were tested for the score of both eyes, the targets in the two eyes would be both like the targets in the “right eye” in figure 2.9). They were requested to keep their both eyes open, although their left eyes only see the background pattern. The subjects were asked questions like “please tell, in target number 2, the circle in which direction is the unbroken one.” The subjects were asked by the sequence of the targets. If they answered one wrong, but the next one right, then the test still went on, until they answered two consecutive wrong answers. Their scores were decided by the last one target they answered correctly.

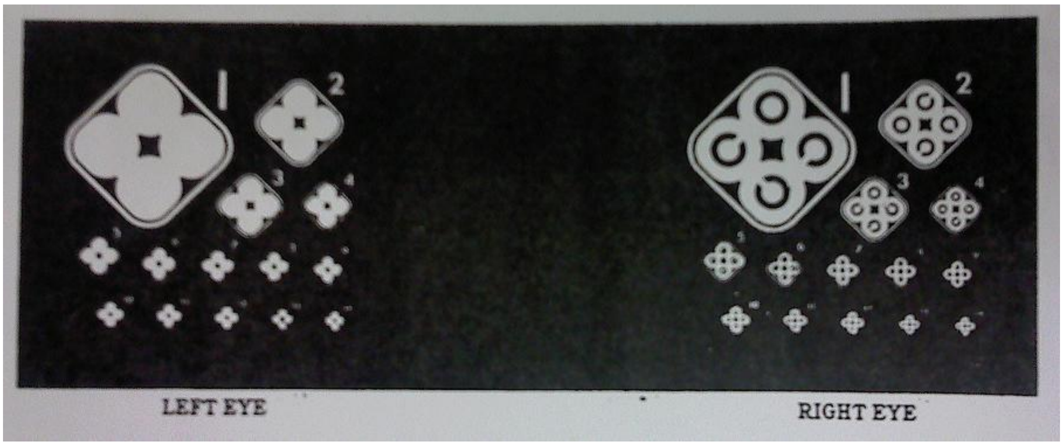

Figure 2.9 An illustration for the vision test.

2.2.2 Line length estimation test

Since free modulus related data was used in the experiments, the line length estimation test was necessary to prove that the subjects get the ability to correctly describe their feelings.

In the line length estimation test, each subject was shown 20 lines drawn on different pieces of paper, with the range from 1 cm to 20 cm. All the lengths of the lines were integers. At first, the subjects were shown how long a line of 1 cm is, and then the other lines were put in front of them one by one randomly. After the subjects gave their estimated numbers to the lengths of the lines, a linear regression model was performed to the numbers estimated by the subjects. Only those subjects who get the R^2 value larger than 0.9 can pass this test.

2.3 Processing methodologies for the dependant variables in the experiment

During the experiments, the subjects were asked for the following 4 dependant variables every 2 minutes.

2.3.1 The 7-point nausea rating data

The first variable is the 7-point nausea rating data proposed by Golding and Kerguelen in 1992. It measures the nausea feeling by 7 different symptoms. During the experiment, every 2 minutes, the experimenter repeated the 7 symptoms in the subjects' native language and the subjects were asked which symptom was the closest one to describe their current feeling. The 7 symptoms are shown in table 2.6. During the data process procedure, rating A was treated as score 1, while rating G was treated as score 7.

Rating	Definition
A	No symptoms
B	Any unpleasant symptoms, however slight
C	Mild unpleasant symptoms, e.g. stomach awareness, sweating but no nausea
D	Mild nausea
E	Mild to moderate nausea
F	Moderate nausea but can continue
G	Moderate nausea, want to stop

Table 2.6 The 7 symptoms in the 7-point nausea rating

2.3.2 Nausea ratio scale data

The nausea ratio scale data was modified from Stevens and McGee (1998). In experiment 1, every two minutes, the experimenter reminded the subjects what number they gave 2 minutes ago. The subjects then gave their new numbers based on the number got 2 minutes ago. If they thought their feeling of nausea had doubled during the past two minutes, they just doubled the number and told the experimenter; if they thought the feeling of nausea was just 1/3 of the previous 2 minutes' feeling, they divided the number by 3 and told the experimenter.

In experiment 2, the data of 0 minute was got at the beginning of the experiment. Unlike in experiment 1, in experiment 2 the subjects were required to close their eyes and gave a number for 0 minute data before they opened their eyes (in experiment 1, they were requested to give the 0 minute data after they opened their eyes). The data of other minutes were got with the same method as in experiment 1. The reason why such method was changed in experiment 2 was due to the second processing method of the nausea ratio scale data.

After the experiment finished, for every subject and every condition, there were 16 numbers for the nausea ratio scale data. There were 2 methods in processing the nausea ratio data and the mean of the processed data was used for analysis in the experiments.

The first method was to use McGee's method:

1. All the raw data was performed a log-transformation first.
2. Then the mean for every subject under every condition was calculated. For each subject, the mean for all the conditions would be calculated. Then the bias for every subject under each condition would be achieved by subscribing the mean of all the conditions from the mean of each condition for that subject.
3. The log transformed data would be subscribed from the bias to get the normalized data.
4. An anti-log transformation would be processed for the normalized data to get the final

data of one subject in one condition.

The second method was much simpler. For every condition of every subject, set the number of the 0 minute's raw data to be 1. Replace the data in the other time by the ratio of the raw data at that time to the raw data in 0 minute.

The reason to change the method in getting 0 minute's data was because the 0 minute raw data was very important in the second processing method. If the 0 minute data was taken when the experiments hadn't started and the subjects were closing their eyes, it's better, especially than taking them after the subjects opened their eyes. Because it was believed that the feelings of nausea before the subjects opened their eyes should be almost the same, or at least were similar for different conditions of each subject.

2.3.3 The SSQ (Simulator Sickness Questionnaire) data

The SSQ was proposed by Kennedy et al in 1993, and it was translated into the subjects' native language for the experimenter to use in the experiments. In each condition, the subjects filled the questionnaire twice. They filled it before they started the experiment, as the pre-SSQ scores. Only subjects with at most 1 "moderate" or 2 "slight" of the symptoms in the pre-SSQ questionnaire were allowed to do the experiments, otherwise they were requested to come in another day, when they were feeling better physically. Such a requirement is also an evidence for the validity of the second method in processing the nausea ratio scale data and changing the method in getting 0 minute data in experiment 2. Because with the pre-SSQ scores very small, it is reasonable to say the feelings of nausea at 0 minute were almost the same for all the subjects.

Another time the subjects were required to fill in the questionnaire was when the subjects had finished one of the conditions of the experiment. The scores achieved would be called post-SSQ scores. Also the subscores like nausea, ocolomotor and disorientation were calculated for further analysis.

2.3.4 Self perceived vection velocity

The self perceived vection velocity is proposed by Webb and Griffin in 2003. The definition of the velocity is shown in table 2.7.

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

Table 2.7 The definitions of the self perceived vection velocity

For the scores of 1~49% and 51~99%, the subjects were required to give a specific number based on the relative speed of their self rotating and the images' rotating speed. For example, if the subjects were feeling that they were rotating 2 times as fast as the speed of the images, no matter the speed was in the same direction or not, they would report a velocity of 2/(1+2) *100 =66.7%, or roughly 70% to the experimenter.

Chapter 3. Experiment 1: Interacting effects of visual velocity and eye fixation on visually induced motion sickness

3.1 Motivation and research gap

Hu et al (1989) had completed a body of research on the effect of the visual stimuli's velocity on the evoked VIMS. In the experiment, subjects were exposed to a certain kind of visual motion. The visual motion was made of alternative black and white striped patterns painted on a rotating drum. The dimensions of the striped patterns used by them were 5.7 degrees for the black and 9.3 degrees for the white. Figure 3.1 illustrates the visual stimuli.

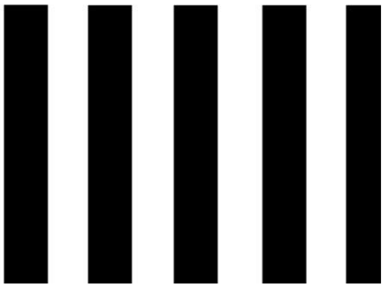

Figure 3.1 An illustration for the visual stimuli used in Hu and Stern's experiments.

In the experiment, the subjects were requested to remain steady in the middle of the rotating drum. Then for the subjects, they could see that the drum was rotating and this rotation would make the subjects relatively feel themselves also rotating (such kind of self rotating feeling is the vection feeling described in section 2.3.4). However, the inner ear vestibular organs of the subjects told them that they were actually standing still. Hence a conflict was generated and the subjects might feel motion sickness.

The speed he chose in the experiment's conditions were 15dps (degree per second), 30dps, 60dps and 90dps. The result can be found in figure 3.2 (SSMS: subjective symptoms of motion sickness). The motion sickness reached the peak at the condition of 60 dps, and it showed significantly greater motion sickness than the other conditions, including the condition of 90 dps. The reason why VIMS in the condition of 90 dps was less than that in the condition of 60 dps was said that due to the high velocity of the visual stimuli, the images projected to the subjects' eyes became blurred and thus evoked less VIMS.

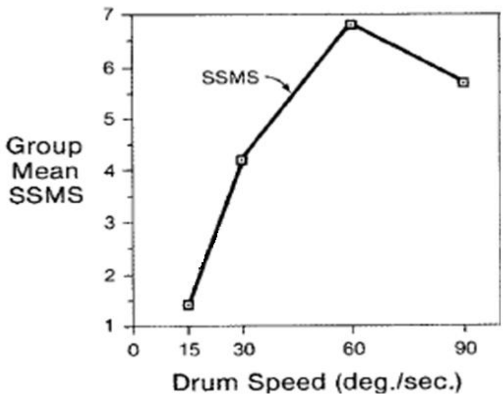

Figure 3.2 A figure for the effects of the stimuli's speed on VIMS cited from Hu's study.

Stern et al (1990) conducted a following experiment on the effect of eye fixation in evoking VIMS. The visual stimuli applied in his experiment were the same as used by Hu (rotating drum and black and white striped patterns). The velocities of the visual stimuli were controlled to be 60 dps in Stern's experiment. The conditions tested by Stern were 60 dps' rotating black and white striped patterns without eye fixation (this condition was exactly the same as Hu's, all the conditions in Hu's experiment didn't have fixation points) and 60 dps' rotating patterns with an eye fixation point at the center of the subjects' field of view. The result can be found in figure 3.3.

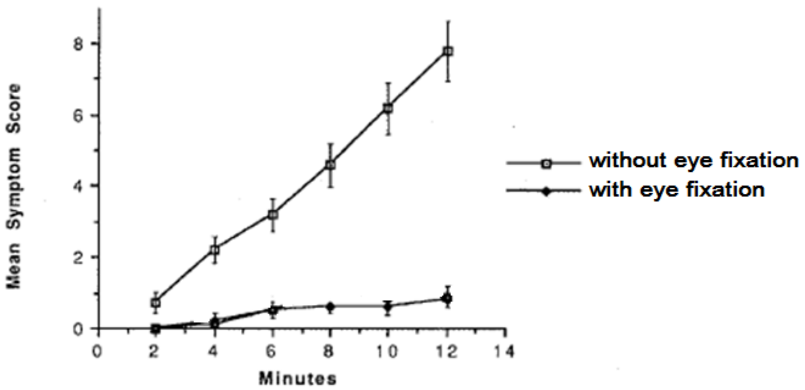

Figure 3.3 A figure for the effects of eye fixation on VIMS cited from Stern's study.

In the result, Stern found that after eye fixated, the subjects felt significantly less motion sickness comparing to the condition without eye fixation, when the velocity of the rotating patterns was 60 dps.

It was concluded that eye fixation can reduce the motion sickness from Stern's study. However, the effect of eye fixation in reducing VIMS may be confounded with the increase in the retinal slip. Retinal slip is the relative velocity of the visual stimuli to the human eyes. The retinal slip was different in the conditions with and without eye fixation. Because in the conditions without eye fixation points, subjects' eyes were drawn by the rotating drum and thus made the retinal slip smaller than the velocity of the drum. The data of the author's experiment showed that in conditions of 60 dps without eye fixation, the velocity of the subjects' eyes reached around 40 dps. This meant the retinal slip in such conditions without eye fixation was only about 20 dps. However, in the conditions with eye fixation, subjects' eyes just focused on the fixation points and made no eye movements. The retinal slip in the conditions with eye fixation was exactly the same with the rotating drum and hence was larger than the conditions having the same velocity of the rotating drum but without eye fixation.

In this experiment, it was hypothesized that such a confounding effect, or can be called as an interacting effect between the speed of the rotating visual motion and the existence of the eye fixation, should be the real factor that affected the VIMS. Stern's study that the motion sickness in the condition of eye fixation was lower could be due to the fact that the retinal slip was larger after the eyes were fixated. Since too quick retinal slip could make the visual motion blurred to subjects, the VIMS evoked was significantly less due to the increase in the retinal slip after eye fixated. This was just as what happened in the condition of 90 dps without eye fixation in Hu's study.

Detailed explanations can be found in the following part.

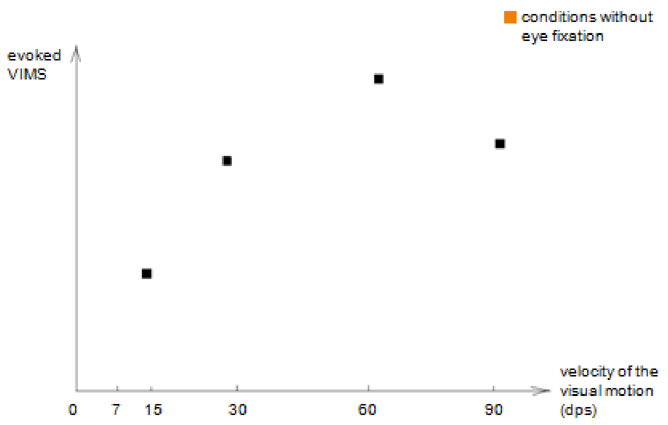

Figure 3.4 The result of Hu's study

Figure 3.4 shows the result of Hu's study, the horizontal axis is the speed of the visual stimuli and the vertical axis is the evoked VIMS. The four conditions he tested are listed as the square points in the figure. As stated previously, he found the motion sickness evoked at the speed of 60 dps was the largest among the others'.

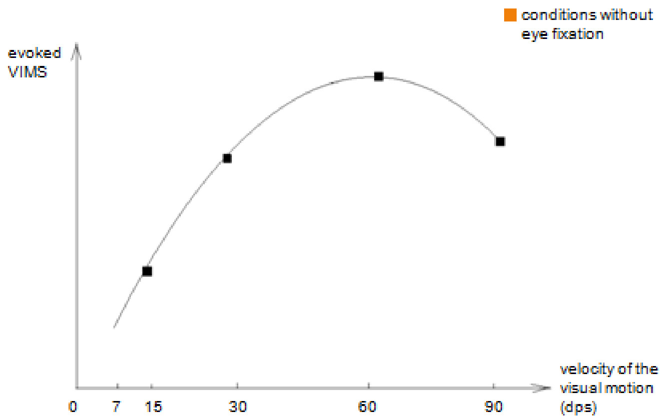

Figure 3.5 The result of Hu's study, with the frequency response curve on it.

From the four points of Hu's study, a frequency response curve can be drawn as shown in figure 3.5.

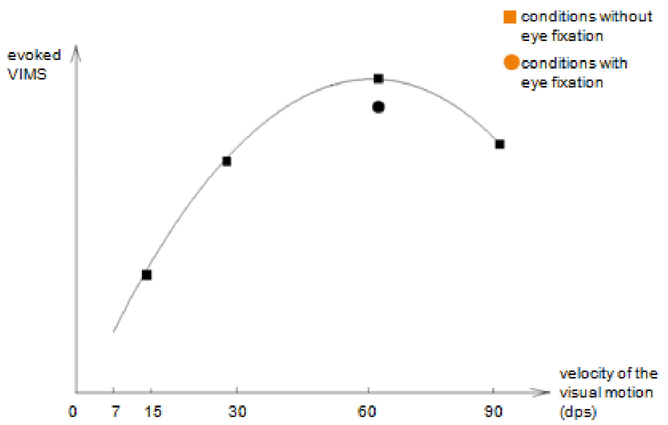

Figure 3.6 The figure for the results found by Hu and Stern

Figure 3.6 shows the result after adding Stern's study in. He tested two conditions, with one to be the same as completed by Hu. The other point is the circle point in the figure, which evoked a less motion sickness comparing to the condition with the same rotating velocity of the visual stimuli but without eye fixation.

If eye fixation really reduces VIMS across all the speed levels of the visual stimuli, then the curve in figure 3.5 would be shifted down after eye fixation, as shown in figure 3.7.

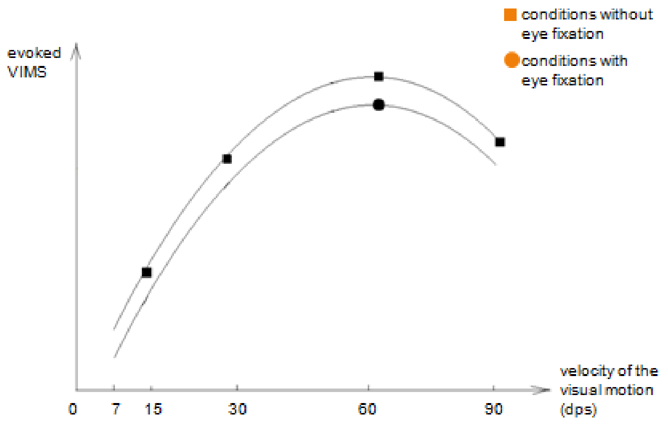

Figure 3.7 The frequency response curve for VIMS, if eye fixation reduces VIMS across all the speed levels of visual stimuli

However, if the real independent variable that evokes VIMS isn't the speed of the visual stimuli but the retinal slip, as it is discussed in the previous paragraphs, the curve in figure 3.6

wouldn't be shifted down but shifted to the left. Because after eye fixation, the retinal slip is always made larger. This means to have a similar retinal slip to evoke similar VIMS, conditions with eye fixation only need a lower velocity of the visual stimuli, comparing to the conditions without eye fixation. And also because retinal slip is always made larger after eye fixation, the frequency response curve can only be shifted to the left after eye fixation, not to the right. If this interacting hypothesis is true, the new frequency response curve after eye fixation would be similar to the one drawn in figure 3.8. A condition with eye fixation but larger VIMS can be expected at the area with low velocity of visual stimuli (shown as the "expected condition" in figure 3.8). The motivation of this experiment is to find whether there exists such an expected condition and whether such an interacting effect is true.

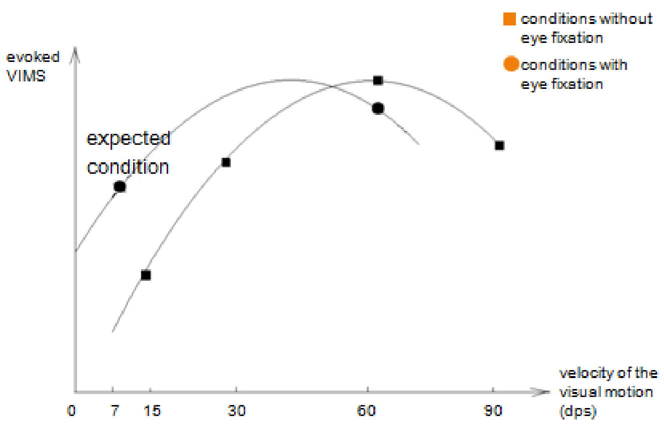

Figure 3.8 The curve for VIMS, if the real independent variable to evoke VIMS is retinal slip

3.2 Hypotheses

There are three hypotheses in this experiment:

H1. Changing the velocity of the visual stimuli can evoke different levels of VIMS

H2. Eye fixation can reduce the VIMS when the velocity of the visual motion is 61.5 dps

H3. Eye fixation can increase the VIMS when the velocity of the visual motion is 6.8 dps

3.3 Experiment design

3.3.1 Experiment variables

3.3.1.1 Independent variables

There were two independent variables in the experiment design, one was the speed of the visual stimuli (low/high) and the other was the existence of the eye fixation (with/without).

3.3.1.2 Dependent variables

Four dependent variables were used in the experiment design. The first one was the 7-point nausea rating as described in 2.3.1. The second one was the nausea ratio scale as described in 2.3.2. The third was the SSQ data as described in 2.3.3. The last one was the self perceived vection data as described in 2.3.4.

3.3.2 Experiment conditions

A 2 by 2 full factorial design was applied in this experiment, with the speed of the visual stimuli and the existence of eye fixation as the two independent variables. The parameters of the conditions are listed in table 3.1.

		Speed of the visual stimuli	
		Slow	Fast
Existence of eye fixation	Yes	A	C
	No	B	D

Table 3.1 The design of experiment 1

The speed of the visual stimuli was chosen to be 6.8 dps for the “slow” level and 61.5

dps for the "fast" level. The reason why such speeds were chosen was due to the following considerations:

1. The basic step in changing the visual stimuli was 6.8 dps, due to the apparatus' constraints. Detailed explanations on the constraints can be found in the appendix A.
2. The "fast" level was set to be 61.5 dps so that a consistency can be shown with Hu's research.
3. For the "slow" level, although it was attractive to have faster speed due to the reason faster speed can evoke larger sickness hence was more probable to give significant results, it was still set to be a very slow speed. Because if a speed like 40 dps was chosen, it would be very probable that two conditions with similar motion sickness might be found (see figure 3.8).

3.3.3 Subjects and experiment sequence

16 subjects including 8 females and 8 males, aging from 20 to 30 were recruited in this experiment. All of them were from mainland China. As there were 4 conditions, they were divided into 4 groups. Each group was designed to be a 4X4 lattin square to randomize the cumulative effect. The lattin square is shown as table 3.2.

Subject \ Sequence	Day 1	Day 2	Day 3	Day 4
I	A	B	D	C
II	B	C	A	D
III	C	D	B	A
IV	D	A	C	B

Table 3.2 The 4 by 4 lattin square in experiment 1

3.4 Procedure

3.4.1 Eyesight test

An eyesight test was performed to screen out the subjects who didn’t have appropriate eyesight required for the experiment. Detailed explanations and the screening criteria can be found in the section 2.2.1.

3.4.2 Line length estimation test

Before the start of the experiment, subjects had to pass the line length estimation test, otherwise they were screened out. Detailed explanations can be found in section 2.2.2.

3.4.3 Pre-SSQ form

Each time the subjects were tested for a specific condition, a pre-SSQ form was completed. If the subjects filled more than one “moderate” or two “slight” in any symptoms, they were required to come in another day for the experiment, as they weren’t feeling well according to the scores of the pre-SSQ.

Detailed explanations can be found in section 2.3.3.

3.4.4 EOG electrodes wearing and the adjustment for the field of view of the eyes

After the subjects finished completing the pre-SSQ form, the experimenter placed 5 electrodes on their face. Detailed explanations can be found in section 2.1.3.

The subjects then stood in front of the screen and a figure with lines indicating different height levels was shown to the subjects. The subjects were asked to pick the line that they thought was at the most comfortable level if they looked to the front. The experimenter then changed the height of the eye fixation point according to the height chosen by the subjects, if an eye fixation point was needed in that condition.

The height for the two points in the mapping test was also adjusted, based on the height chosen by the subjects. (Detailed explanations on the mapping test can be found in section 2.1.3.) The mapping test was then performed.

3.4.5 Polhemus setting

After the mapping test, the subjects then performed the required posture of the experiment (as shown in figure 2.5) and got ready for the experiment. A belt with the Polhemus sensor was worn by each subject in the experiment. The transmitter was placed approximately 30 cm away from the sensor. The Polhemus would then "re-initialize to the power up state" and be boresighted to make the 3 angles it tested to be reset to zero.

Detailed explanations on Polhemus can be found in section 2.1.2.

3.4.6 Start of the visual exposure

After all the preparations were completed, the subjects were required to close their eyes. The visual stimuli on the screen began to rotate and the EOG and Polhemus started to record the data. The subjects then opened their eyes and reported their feelings for the dependent variables on the 0 minute. Then the subject kept on reporting the feeling for the dependent variables at every two minute intervals until the end of the experiment at 30 minutes or when they felt it was too difficult to continue with that condition (report level G in 7-point nausea rating). At any time, if the subjects felt they couldn't continue with the experiment and requested to stop, the experimenter immediately halted the experiment. And in such cases, all data for the rest of the time was replaced by the last data received from the subject.

After the experiment was finished, the apparatus was also stopped and the subjects need to complete the post-SSQ form.

3.5 Results and discussions

3.5.1 Conclusions on the hypotheses and key evidences

Hypothesis 1 is accepted. The Anova test for the mean 7-point nausea data showed that the main effect of speed is significant ($p= 0.002$). Although the mean 7-point nausea data passed the normality test ($p> 0.05$, detailed explanations can be found in appendix D), Wilcoxon test was still run to ensure the result of the Anova test. The Wilcoxon test showed that the VIMS evoked by the conditions with eye fixation and without eye fixation was significantly different ($p= 0.00$). This means changing the velocity of the visual stimuli from 61.5 dps into 6.8 dps significantly reduced the VIMS. Hu's study showed that when changing the velocity of the visual stimuli from 60 dps into 30dps or 15dps, the VIMS is significantly reduced, but the condition of 6.8 dps was first tested here.

Hypothesis 2 is also accepted. Paired-Sample T test showed that eye fixation can reduce VIMS significantly for the mean 7-point nausea data ($p= 0.014$) at conditions with 61.5 dps. The Wilcoxon test also showed that such reduce was significant ($p= 0.024$). Hence this result showed a consistency with Stern's study.

For hypothesis 3, it was significantly rejected. Because Paired-sample T test for the mean 7-point nausea data between the conditions with eye fixation and without eye fixation showed significant difference ($p= 0.034$). And Anova test for the interaction effect between speed and eye fixation wan't significant ($p> 0.05$).So hypothesis 3 was significantly rejected as nausea was considered to be significantly reduced in the conditions of both speeds after eye fixated, although neither further Paired-Sample T test nor the Wilcoxon test showed that such reduce was significant at the conditions with low speed (both $p > 0.05$). Possible reasons may due to that the nausea evoked at that speed wasn't quite large. Figure 3.9 shows the plot for the mean 7-point nausea data in experiment 1.

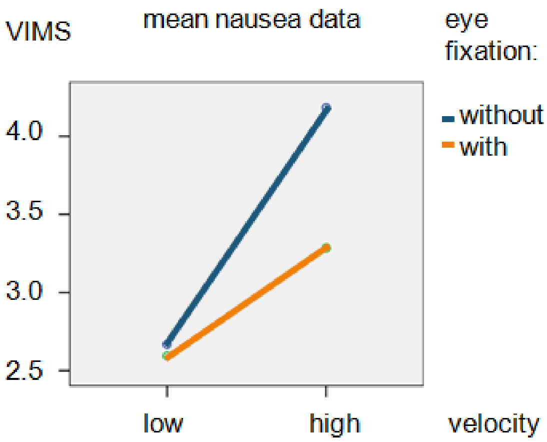

Figure 3.9 Plot for the mean 7-point nausea data in experiment 1.

3.5.2 Supplementary evidence on the hypotheses

Survival analysis test was run for the 7-point nausea data in this experiment. The result of the test for the subjects to get a feeling of level "D" (start to feel nausea) is shown table 3.3.

Condition	Med Time (minutes)
A: 6.8 dps with eye fixation	30.0000
B: 6.8 dps without eye fixation	26.0000
C: 61.5 dps with eye fixation	15.3333
D: 61.5 dps without eye fixation	12.0000

Table 3.3 Median survival time table for the subjects to get a level of D in 7-point nausea rating in experiment 1

It can be found that, for both levels of the visual stimuli's speed, the survival time extended to 3~4 minutes longer after the eyes were fixated. The survival time was shorter under the conditions of higher speed. The result of the survival time analysis consisted with the discussion in 3.5.1.

3.5.3 Further tests on the time effect on nausea and vection at every 2 minutes.

The Anova test using repeated measures was run to see the time effect on the nausea and vection during the 30 minutes experiment for all the subjects.

The result shown in table 3.4 was that there was a significant time effect on the 7-point nausea data collected in the experiment and the interaction effect between the nausea data and the velocity of the visual motion in the conditions was also significant. Possible reasons may be that visual stimuli at higher speed can evoke greater VIMS in the experiments, so the nausea difference collected at different speed conditions became greater as time went on. For the interaction effect between nausea and eye fixation, the Greenhouse-Geisser test and the Lower-bound test both showed an insignificant effect, while the Huynh-Feldt test showed a significant effect with *p* just equal to 0.05. However, considering that the Huynh-Feldt test is the least conservative test among the three tests, the interaction effect between time and eye fixation was believed to be insignificant.

Source	Test	Sig.
nausea	Greenhouse-Geisser	0.00
	Huynh-Feldt	0.00
	Lower-bound	0.00
nausea * eyefixation	Greenhouse-Geisser	0.06
	Huynh-Feldt	0.05
	Lower-bound	0.10
nausea * speed	Greenhouse-Geisser	0.01

	Huynh-Feldt	0.01
	Lower-bound	0.05
nausea * eyefixation * speed	Greenhouse-Geisser	0.40
	Huynh-Feldt	0.41
	Lower-bound	0.34

Table 3.4 Time effect on the 7-point nausea evoked in experiment 1.

For the vection data (normality test p>0.05, detailed explanations can be found in appendix D), as shown in table 3.5, there was a significant time effect on the vection feeling during the whole experiment. There was no interaction effect between the time and the other factors.

Another interesting finding on vection was that Wilcoxon test showed that eye fixation had a significant effect on the vection rating at 0 minute in the conditions both at higher speed and lower speed (p=0.012), but not on the other minutes except for the data at 6^{th} minute (p=0.015). The significant effect on the difference of vection data at 0 minute indicated that vection feeling evoked at a very short duration was highly affected by the existence of eye fixation (such duration maybe less than 20s, which was the time for the experimenter to ask subjects about the question of vection).

Source	**Test**	**Sig.**
vection	Greenhouse-Geisser	0.00
	Huynh-Feldt	0.00
	Lower-bound	0.00
vection * eyefixation	Greenhouse-Geisser	0.20
	Huynh-Feldt	0.18
	Lower-bound	0.24
vection * speed	Greenhouse-Geisser	0.69
	Huynh-Feldt	0.72

	Lower-bound	0.42
vection * eyefixation * speed	Greenhouse-Geisser	0.38
	Huynh-Feldt	0.38
	Lower-bound	0.30

Table 3.5 Time effect on the vection evoked in experiment 1.

3.5.4 Result for the data of Polhemus

The data got by the Polhemus was used as the evidence that the subjects didn't have huge movements during the experiments. The SD of the body movements confirmed with it. The SD of the up-and-down axis was 0.50 cm; the SD of the left-and-right axis was 0.60 cm; the SD of the fore-and-back was 0.56 cm.

Chapter 4. Experiment 2: Isolating the effects of foveal retinal slip velocity and eye motion on Visually Induced Motion Sickness

4.1 Motivation

As experiment 1 found that eye fixation, or stationary eye movement, successfully suppressed VIMS at both speed levels of the visual motion. It was believed that the effect of eye fixation was to reduce the VIMS.

Similar result was also confirmed by Webb (2000), when using different apparatus. In 2000, Webb tested the effect of eye fixation when the velocity of the visual stimuli was 30 dps. The visual stimuli Webb used were still the black and white striped patterns. However, the apparatus Webb used was a head mounted display (HMD), instead of the rotating drum which can provide a full field of view. The HMD can only provide a field of view for about 40 degrees. Lin et al (2002) confirmed that the field of view had a significant effect on the VIMS. Hence Webb's conditions weren't merged into the figure 3.8, as they were studies from a different field of view.

Since the effect of eye fixation was already believed to reduce the VIMS in the previous studies, especially in experiment 1, the next question would be why eye fixation can reduce the VIMS, or what property of eye fixation makes the VIMS reduced.

The eye fixation in experiment 1 refers to two things: (i) zero foveal retinal slip velocity; (ii) zero eye movement velocity. The subjects had zero foveal retinal slip velocity in the experiment was because they were looking at a solid fixation point, not an open fixation point. The zero eye movement was due to the reason that the subjects focused their eyes on the fixation point, and made no eye movements at al. So it is interesting to ask, which one of the two properties should be responsible for the reduced VIMS? Or are they both responsible?

The motivation of experiment 2 was just to isolate the two effects and test which one should be responsible for the reduced VIMS.

4.2 Hypotheses

Three hypotheses were tested in this experiment:

H1. When the visual velocity is 34 dps, eye fixation can reduce the VIMS.

H2. When the visual velocity is 34 dps and the foveal retinal slip velocity is zero, eye motion can increase the VIMS.

H3. When the visual velocity is 34 dps and the eye movement is similar, the foveal retinal slip can increase the VIMS.

4.3 Experiment design

4.3.1 Independent variables

There were two independent variables in the experiment: (i) foveal retinal slip velocity (zero/non-zero); (ii) eye movement velocity (zero/non-zero).

4.3.2 Experiment conditions in the pilot study of experiment 2

Four conditions with a full factorial design were tested at the pilot study at the beginning, but one condition was dropped due to the reason that it couldn’t provide satisfied visual motion as it was supposed to be. Figure 4.1 shows the visual stimuli used in the pilot study for the four conditions. Condition A, B and C were adopted in the experiment 2, while condition X was dropped.

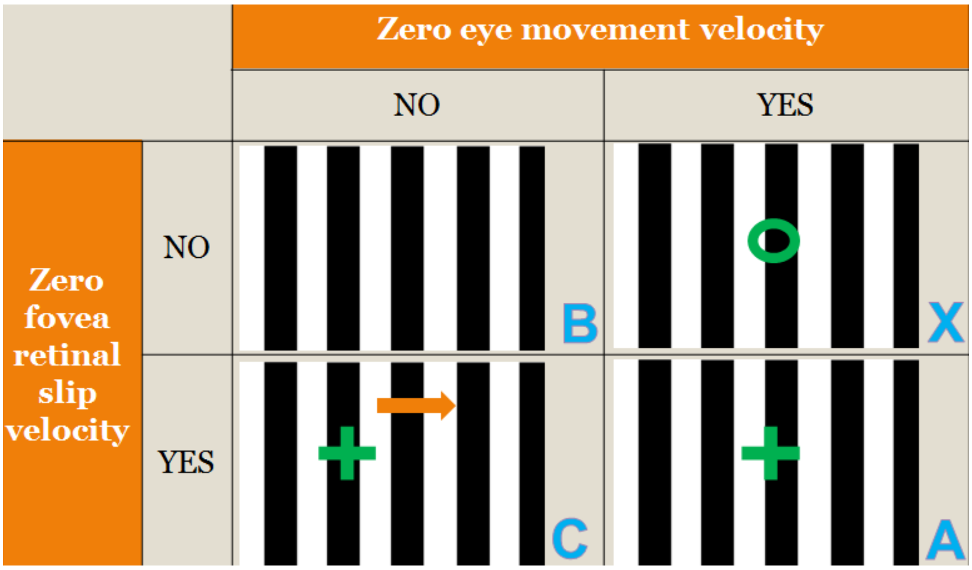

Figure 4.1 Four conditions tested in the pilot study of experiment 2.

Condition A was similar to the conditions with eye fixation in experiment 1, because subjects were required to rest their eyes on the fixation point. In condition A, subjects were supposed to have zero eye movement velocity and zero foveal retinal slip velocity. Condition B was similar to the conditions without eye fixation in experiment 1, because subjects could move their eyes in this condition. In condition B, the subjects had non-zero foveal retinal slip velocity and non-zero eye movement velocity. Condition C had the black and white striped patterns rotating, but at the same time, the fixation point was also moving. In condition C the subjects were required to follow the moving fixation cross as much as possible. By doing this, the foveal retinal slip velocity of the subjects in condition C would be zero, because their eyes were relatively stationary to the moving fixation cross. However, they still had non-zero eye movement velocity, since their eyes were still moving.

Condition X was dropped. In condition X, the subjects were supposed to look into the open circle and not to let their eyes move beyond the circle. By using this open circle, the subjects' eye movements were restricted and the velocity could be almost zero, while at the same time, the foveal retinal slip was still non-zero because they can see the visual motion in the center of the circle. However, after the pilot study, most of the subjects gave their feedbacks as they couldn't see the patterns moving in the center of the circle, but flashing for alternative black and white. The reason they thought was that the circle was too small to have a clear view of the whole visual motion. But since the circle was used to restrict the eye movements, it can't be too big. So the condition X was finally dropped because it can't give the subjects a feeling of moving, but flashing.

4.3.3 The parameters of the moving cross in condition C

To test on the hypothesis 3, that when the visual velocity is 34 dps and the eye movement is similar, the foveal retinal slip can increase the VIMS. The VIMS evoked by condition B and C need to be compared. But one thing needs to be ensured before the comparison of the VIMS is made: the eye movements for the subjects in condition B and C should be similar. Since eye movement in condition B is just decided by the background, which is the same as condition C, the only way to make the eye movements similar was to manipulate the parameters of the moving fixation point in condition C so that the eye movement parameters in condition C could be similar to condition B.

Two key parameters considered in the experiment design were the mean SPV and the mean amplitude per OKN cycle. Explanations on SPV and OKN can be found in section 2.1.3. Before all the subjects started the 3 conditions of the experiment, they were requested to participate in a 5 minute pre-exposure to condition B which obtained their eye movement data through the EOG apparatus. Their mean SPV was 25.96 dps and the mean amplitude per OKN cycle was 9.69 degrees in the 5 minute pre-exposure. However such data was not directly used in the experiment design. Further considerations like the constraints of the apparatus and a compensate time for the saccades were discussed to finally get the parameters of the moving cross in condition C.

Given the constraints of the apparatus that the basic step in changing the speed of the cross was 6.833dps (detailed explanations can be found in the appendix A), the speed of the moving cross was set to be 6.833*4 = 27.33 dps, which was the closest to the mean SPV of the subjects.

To calculate the compensate time for the saccades, some literature was referred to obtain the result.

Bahill et al (1975) found the relationship between the amplitude (or can be called as magnitude) and the duration for a saccade. Figure 4.2 is directly cited from their paper to show the relationship. From the figure, it can be found that the duration for a saccade with the magnitude about 10 degree is about 0.041s

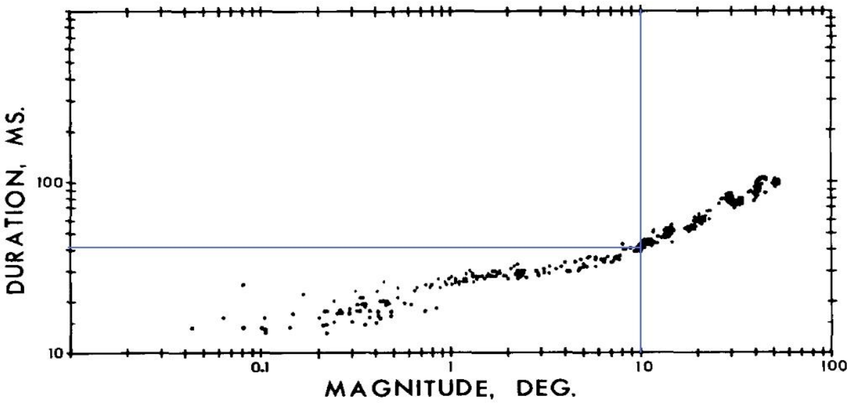

Figure 4.2 The figure showing the relationship between the duration and the magnitude of a saccade cited from Bahill's study.

Kaminiarz (2009) formed an equation of how long it will take for a saccade with certain amplitude. The equation is $T = 17.83*A^{0.38}$, while T represents for the duration and A represents for the amplitude. The duration for a saccade with amplitude of 9.69 degrees, according to the equation, was 0.042s. Since the result of 0.042s was got from an equation, which meant it's more precise, and it's highly consistent with the result of Bahill, 0.042s was considered as the saccade duration for a typical OKN of the subjects in the condition B.

Given the speed of the moving cross, 27.33dps, the amplitude of the cross's movement was set to be 0.042*27.33+9.69=10.84 degrees. Again, due to the constraints of the apparatus, the closest magnitude can be made was 10.64 degrees. So the final parameters of the cross movement were 10.64 degrees for the amplitude, 27.33 for the speed and the cycle time for the cross movement was 0.39 seconds. Some validity discussion like whether the parameters of the subjects' eye movements are repeatable or whether they change with different shapes of the moving point (a cross or a square) can be found in the appendix B and C. Within the constraints of the apparatus, those time effect and the shape effect won't change the final parameters of the moving point in the experiment design.

4.3.4 Conditions used in the experiment 2

Three conditions were finally used in the experiment 2, detailed parameters of the conditions are the following:

Condition A: 34 dps with a fixing cross

Condition B: 34 dps without eye fixation

Condition C: 34 dps with a tracking cross, the amplitude of the cross is 10.84 degrees and the speed of the cross is 27.33 dps

4.3.5 Dependant variables

The dependent variables used in this experiment were the same as the four dependent variables used in experiment 1. The first one was the 7-point nausea rating as described in 2.3.1. The second one was the nausea ratio scale as described in 2.3.2. The third was the SSQ data as described in 2.3.3. The last one was the self perceived vection data as described in 2.3.4.

4.3.6 Subjects and experiment sequence

15 subjects including 8 females and 7 males, aging from 20 to 30 years old were recruited in this experiment. All of them were from mainland China. As there were 3

conditions in the experiment, they were grouped into 5 groups, with each group designed into a 3 by 3 lattin square to randomize the cumulative effects in the experiment.

4.4 Procedure

The procedure of this experiment was the same as experiment 1, except for two changes. The first was that one week before the main experiment started, subjects were required to participate a 5 minute pre-exposure to condition B to obtain their eye movement data. The second was the method in getting the nausea ratio scale data of the 0 minute was different. Detailed explanations can be found in section 2.3.2 and 4.4.6. The procedure of the main experiment was listed again here.

4.4.1 Eyesight test

An eyesight test was performed to screen out the subjects who didn't have the appropriate eye sight required for the experiment. Detailed explanations and the screening criteria can be found in the section 2.2.1.

4.4.2 Line length estimation test

Before the start of the experiment, subjects need to pass the line length estimation test, otherwise they were screened out. Detailed explanations can be found in section 2.2.2.

4.4.3 Pre-SSQ form

Each time the subjects were tested for a condition, a pre-SSQ form was filled. If the subjects gave more than one “moderate” or two “slight” for any of the symptoms, they were required to come in another day for the experiment. The reason for this was that they weren't suitable to start the experiment if they felt uncomfortable.

Detailed explanations can be found in section 2.3.3.

4.4.4 EOG electrodes wearing and the adjustment for the field of view of the eyes

After the pre-SSQ form had been completed, the experimenter placed 5 electrodes on the face of each subject. Detailed explanations can be found in section 2.1.3.

The subjects then stood in front of a screen and a figure with lines indicating different height levels was shown to the subjects. The subjects were asked to pick the line that they think was at the most comfortable level if they looked into the front. The experimenter then changed the height of the eye fixation point according to the height chosen by the subjects, if an eye fixation point was needed in that condition.

The height for the two points in the mapping test was also adjusted, based on the height chosen by the subjects. (Detailed explanations on the mapping test can be found in section 2.1.3.) Then the mapping test was performed.

4.4.5 Polhemus setting

After the mapping test, the subjects were required to perform the required posture of the experiment (as shown in figure 2.5) and got ready for the experiment. A belt with the Polhemus sensor was wore by the subjects at this moment. The transmitter was placed around 30 cm away from the sensor. Then the Polhemus would "re-initialize to the power up state" and be boresighted to make the 3 angles it tested to be reset to zero.

Detailed explanations on Polhemus can be found in section 2.1.2.

4.4.6 Start of the visual exposure

After all those preparations, the subjects were required to close their eyes and report their feeling on the nausea using the free modulus method for the 0 minute data. Then the visual stimuli on the screen started to rotate, the EOG and the Polhemus started to record the data. The subjects opened their eyes and report their feelings for the other dependent variables on the 0 minute. For the following every 2 minutes, the subjects reported their feelings for all the dependent variables until the 30th minutes or when they felt it's too hard for them to go on with that condition (report level G in 7-point nausea rating). At any time, if the subjects felt that they can't go on with the experiment and requested to stop the experiment, the experimenter would stop the experiment immediately. In such cases, all the data for the rest of the time would be replaced by the last data got from the subject.

After the experiment finished, the apparatus were stopped. The subjects finished the post-SSQ form before they left.

4.5 Results and discussions

H1 is accepted as the Paired-Sample T test showed that the mean 7-point nausea rating data were significantly different between condition A and condition B (p=0.015). The nausea evoked at condition B was larger than that in condition A. Such result showed a good consistency with Webb's study, that eye fixation can reduce VIMS, comparing to the conditions without eye fixation. Although mean 7-point nausea rating data passed the normality test (p>0.05, detailed explanations can be found in appendix D), further Wilcoxon tests were run to ensure the result. The Wilcoxon tests showed that free modulus data (p=0.056), post SSQ data (p=0.088) and nausea subscore of SSQ (p=0.093) had marginal differences, while the mean and median 7-point nausea rating data were significantly different (*p*=0.009 and 0.004) under the Wilcoxon test.

H2 is also accepted as Paired-Sample T test showed that the mean 7-point nausea rating data evoked by condition A and condition C were significantly different (*p*=0.048). This meant changing the velocity of eye movement can significantly change the evoked VIMS. Further Wilcoxon test showed that free modulus data (*p*=0.026), post SSQ data (*p*=0.012), the nausea subscore of SSQ (*p*=0.016), mean and median 7-point nausea rating data (*p*=0.009 and 0.007) were all significantly different between the two conditions.

For H3, neither Paired-Sample T test nor the Wilcoxon test showed any significant difference between the nausea data got under condition B and condition C (*p*>0.05), except the mean of vection data showed a marginal (*p*=0.087) difference between the two conditions under the Wilcoxon test. The VIMS evoked by the condition C was slightly larger than that evoked by the condition A, although not significant. Further Wilcoxon test on the detailed symptoms of SSQ showed that there was a significant difference in the drowsiness evoked by the two conditions. The drowsiness evoked by the condition C was significantly (*p*<0.05) larger than that evoked by condition A.

However, before making final conclusions on the H3, the eye movement parameters need to be checked and some screening work was also needed to make sure the eye movements were similar in the two conditions.

Paired-Sample T test and Wilcoxon test were run to see whether the differences of the eye movement parameters between the two conditions were significant or not. Paired-sample T test showed that the mean SPV in condition B was significantly larger than that in condition C (23.63 and 20.15 dps, *p*=0.012). Wilcoxon test showed that the mean amplitude per OKN cycle in condition B was significantly larger than that in condition C (10.86 and 8.59 degrees, *p*=0.015)

Since significant differences of the eye movement parameters were shown in the Paired-Sample T test and Wilcoxon test, 4 subjects' data which had the largest difference in the eye movement parameters were screened out. After the screening, the Wilcoxon test showed that there was no significant difference between the eye movement parameters in the two conditions. And the result was, after removing 4 subjects, neither the Paired-Sample T test nor the Wilcoxon test for the nausea comparison between those two conditions changed much (p still larger than 0.05), only the vection changed from marginal difference into insignificant difference ($p>0.05$). Such a result means when the eye movement parameters are similar, changing the velocity of the foveal retinal slip won't change the evoked VIMS significantly.

The SD of the three axis were still calculated to prove that the subjects didn't have much body movements during the experiments. The SD of the up-and-down axis was 0.54 cm; the SD of the left-and-right axis was 0.68 cm; the SD of the fore-and-back was 0.54 cm.

Chapter 5. Discussions and conclusions

5.1 Discussions

5.1.1 The role of eye fixation: shifting the frequency response curve of the visual motion

As discussed in the motivation part of the first experiment, although previously researches had been done to study the effect of eye fixation and the results showed that eye fixation can reduce the VIMS, it was still too early to say the role of eye fixation was to reduce the VIMS across all the frequencies of the visual motion. Because it was possible that the eye fixation's effect was to increase the retinal slip and thus made the frequency response curve of the visual motion shifted to the left (figure 5.1). However, after the first experiment was conducted, it was confident to say that the role of eye fixation was to reduce the VIMS, across all the frequencies of the visual motion (figure 5.2), as two new conditions (shown in the circle) with low velocity were tested.

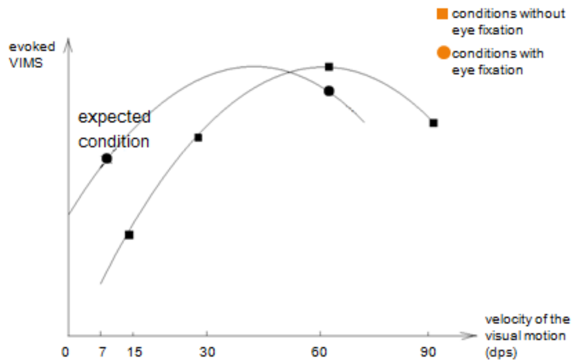

Figure 5.1 The frequency response curve of the visual motion, suppose the eye fixation can shift the curve to the left.

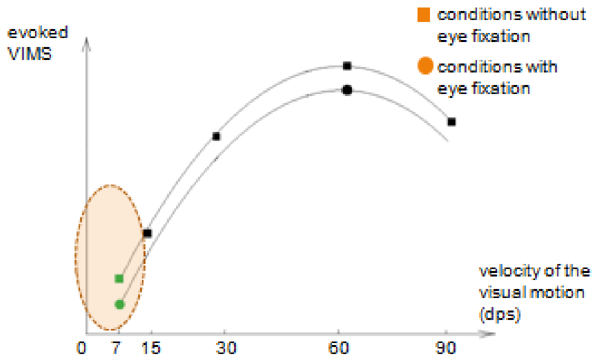

Figure 5.2 The frequency response curve of the visual motion, suppose the eye fixation can shift the curve to the bottom.

5.1.2 The implications of the studies in this thesis

As it is said at the beginning of this thesis, the increase in the access of the video/computer games is one of the reasons that why VIMS is being paid more and more attention to nowadays. The results of the studies in this thesis can be applied to the design in the video/computer games to help avoiding evoking large VIMS in the game play.

One finding in experiment 1 is that changing the velocity of the visual stimuli can significantly affect the VIMS and slow velocity would evoke low VIMS. Hence the game designers need to avoid having quick visual motion in the games. Also, as it was studied previously, extremely quick visual motion could still evoke low VIMS, because the visual motion became blurred to people if they were too quick. So game designers need to choose either a slow velocity of visual motion in the games or an extremely quick visual motion. Some moderate fast visual motion which can reach the peak in evoking the VIMS is strongly not recommended in the game design.

Another finding in the studies of this thesis is that eye fixation can reduce the motion sickness, and such reduce is due to the zero eye movement velocity. So game designers need to try to always set a certain kind of fixation point in the games. Such a fixation point doesn't need to have zero foveal retinal slip velocity, as it was found in the experiment 2 that zero foveal retinal slip velocity wasn't the real factor that should be responsible for the reduce in VIMS. An example of the application for this finding could be that first-person-angle games should always have something to let the character hold, so that it can show up in the screen, like holding a gun. By doing this, the players would always be able to see a "fixation point" during the game play.

5.1.3 Comparison on the two free modulus methods.

In experiment 1, both of the free modulus data processed by the two methods showed significant correlation ($p<0.05$) with the nausea data, but insignificant correlation with the SSQ related data. They also showed significant correlation ($p<0.05$) with each other. And the McGee's method performed better than the other method by showing a marginal significant correlation ($0.05<p<0.10$) with the vection, while the other method failed to do so.

In experiment 2, both of the two methods showed significant ($p<0.05$) correlation with the vection and SSQ related data. But the McGee method failed to show a significant ($p>0.05$) correlation with the nausea related data, while the second method successfully showed a significant ($p<0.05$) correlation with the nausea related data.

Such changes in the correlation result are considered to be due to the change in the procedure of the two experiments. In experiment 1, the subjects didn't need to give their free modulus feeling at the beginning of the 0 minute when they closed their eyes. They can tell the feeling after they opened their eyes, and some subjects did start with a level C in the 7-point nausea, which means the validity of the second method (setting the free modulus data at 0 minute to be 1) wasn't very good in experiment 1. This was also why in experiment 2, every subject was requested to give the free modulus data at the beginning of the 0 minute when they were closing their eyes, to make the nausea feeling at 0 minute to be almost the same across different conditions and so the second method can be valid.

5.2 Conclusions

5.2.1 Interactions between the speed of visual motion and the presence of optokinetic nystagmus (OKN)

The speed of the visual motion can significantly affect the levels of VIMS. As the speed reduces from 60 dps to 7 dps, levels of nausea and simulator sickness questionnaire scores can significantly reduce ($p<0.01$). This suggests that as the retinal slip (movement of images projected on the retinas) reduces, levels of VIMS reduces. Since the presence of OKN enables the eyes to follow the visual motion and reduce the retinal slips, it has been hypothesized that when viewing visual patterns rotating at 7 dps, the presence of OKN will reduce the retinal slip and reduces the levels of VIMS. This is not the case and the presence of OKN when watching patterns rotating at 7 dps actually causes the levels of sickness among viewers to increase. This indicates that, when watcing patterns rotating at 7 dps, the significant effects on levels of VIMS due to the presence of OKN are mainly due to the presence of eye movements and not the associated reduction of retinal slip velocity. The second experiment in this thesis continues the investigation on why the presence, or the lack, of eye movements will affect levels of VIMS.

5.2.2 Isolating the effect of zero foveal retinal slip velocity and zero eye movement velocity

Reducing the velocity of the eye movement can significantly reduce the evoked VIMS

(p<0.05), while reducing the velocity of the foveal retinal slip does not affect the evoked VIMS significantly (p>0.05). As zero foveal retinal slip velocity and zero eye movement velocity are the two properties associated with eye fixation, our results indicate that the lack of eye movement rather than zero foveal retinal slip velocity (i.e., resting your eyes on the same marker) is the dominating factor behind the effects of eye fixation on levels of VIMS.

5.3 Further research directions

Due to the apparatus constraints, the control of eye movement in the second experiment was not perfect. Also, the condition with zero eye movement and non-zero foveal retinal slip velocity in the second experiment was dropped because the subjects felt that the visual motion inside the open circle was flashing instead of moving. Further experiments to smoothout these technical imperfection are desirable.

In this study, the effects of OKN and its associated effects of reducing retinal slip velocity has been studied in isolation with patterns rotating at 7 dps. Similar studies at other pattern rotating speeds should be conducted. In this study, the presence of voluntary smooth pursuit eye movements on a background of rotating patterns has been shown to increase levels of VIMS. It would be interesting if the presence of voluntary eye movement can still increase the levels of VIMS over a background of stationary patterns.

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Appendix A: calibration for the experiment apparatus

1. Calibration of the center point position of the 3-projector screen:

Although the 3 screens provide the stimulus together, obviously it is the mid-screen's stimulus that is most affective to the subject. So the center of the cylinder was defined by the 3-projector screen by finding a point that has almost the same distance with the two edges and the center of the mid-screen, as it is shown in the figure A.1.

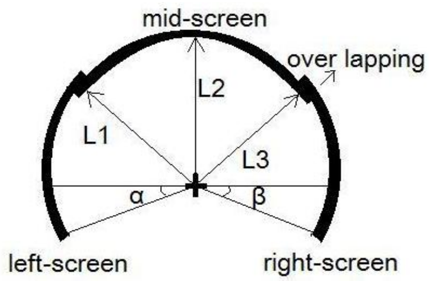

Figure A.1 An illustration of the 3-projector screen uesd in the experiment and the definations of the α and β angle. The "+" sign represants the center of it. The whole field of view of the 3-projector screen is 205.9°.

In the calibration, the distances were measured to be L_1=116.0 cm, L_2=115.6 cm, L_3=117.0 cm. The maximum difference is 1.4 cm, and the mean of the radius is 116.2 cm, the error is 1.2%.

2. Calibration of the field of view of the 3-projector screen:

The field of view was measured by an angulometer. There was a straight line that passed through the center point which was just defined. The α angle was defined as the angle that how much did the left-screen exceed the line, and the β angle was defined as the angle that how much the right-screen exceed the line. The definition can also be found in the figure A.1. Each angle was measured 3 times, the data is shown in table A.1.

	1st measurement	2nd measurement	3rd measurement
α	11.5 °	11.5 °	11.8 °
β	14.5 °	13.9 °	14.4 °

Table A.1 The data measured for the α and β angle.

The mean of α is 11.6 °, the maximum difference is 0.3 °, the error is 2.6%. The mean of β is 14.3 °, the maximum difference is 0.6 °, the error is 4.2%. The field of view is 205.9 °totally.

3. Calibration of the stimulus:

3.1. The field of view of a black and white striped stimulus pattern:

An angulometer was put at the center point. The angles of 3 pairs of the patterns were measured based on this point. That is, 3 black patterns and 3 white patterns. The angle was measured 3 times. They were 46.3 °, 45.9 ° and 46 °. So the mean angle for 1 pair of patterns is 15.4 °. As the stimulus was designed to follow Hu et al (1989), in whose experiment the degrees for 1 pair was exactly 15 °. The error is 2.4%, comparing to their research.

3.2. The velocity of the stimulus:

The velocity of the stimulus was calculated by measuring the time that a pattern would take from when it appeared at the left-screen to when it disappeared at the right-screen. The data is shown in table A.2.

condition	1^{st}(s)	2^{nd}(s)	3^{rd}(s)	Mean(s)	Speed	Error(%)
6.8 dps with eye fixation	30.13	29.90	29.78	29.94	6.88	1.14
6.8 dps without eye fixation	29.97	29.88	30.03	29.96	6.87	1.06

61.5 dps with eye fixation	3.56	3.47	3.41	3.48	59.17	3.79
61.5 dps without eye fixation	3.59	3.44	3.5	3.51	58.67	4.61

Table A.2 The data measured for the velocity of the black and white striped stimulus pattern.

4. Calibration for the Polhemus tracker system:

4.1. Definitions of the x, y and z axis:

The origin of the coordinate used in the calibration was defined at the center of the transmitter. The x axis was defined as the line that was vertical to the ground and passed through the center of the transmitter. The y axis was defined as a line that was vertical to the x axis and passed through the center of the transmitter; it was also vertical to the line that passed through the center of the mid-screen and the center of the cylinder shaped by the 3 screens. The z axis was defined according to the LEFT hand rule. The definition can also be seen from the figure A.2.

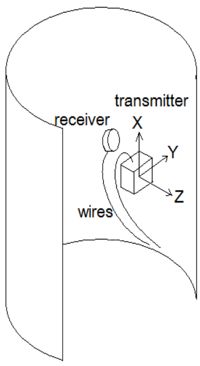

Figure A.2 Definitions of the x, y, z axis.

4.2. The range of the receiver in the calibration:

The calibration was carried out in the condition that was very similar to the experiment. As in the experiment, the receiver would be pasted at the back of the subject. The receiver wouldn't be too far away from the transmitter. The position set in the calibration was to keep the receiver in a hemisphere, which had the center at the transmitter and a radius of 30 cm. That was, the receiver was set in the range of 0~30 cm in the x axis direction, -30~30 cm in the y axis direction, -30~30 cm in the z axis direction.

4.3. The procedure:

The Polhemus tracker system was calibrated in the x, y, z directions and in the azimuth, elevation, roll angles. For the x, y, z directions, the calibration was carried out by using a ruler to make it paralleled to one axis, and moving the receiver of the Polhemus tracker system along the ruler in a certain distance. Then the distance measured by the Polhemus tracker system was then shown on the computer. For the azimuth, elevation, roll angles, an angulometer was used to make sure that the receiver had been rotated in a certain angle. Then the angles shown by the Polhemus tracker system would be compared with that certain angle. Each calibration was measured 6 times, with 3 times in the positive direction and 3 times in the negative direction.

The distance set for the x, y, z directions was 10 cm, and the angle for the azimuth, elevation and roll was 30 degrees. If the subject moved a larger distance than 10 cm or rotated a larger angle than 30 degrees, the experimenter could be able to observe such movement clearly and ask the subjects to avoid such big movements, so any larger distance or angle weren’t calibrated.

4.4. The results:

4.4.1. Calibration in x direction:

	X(cm)	Y(cm)	Z(cm)	x (relative)	y (relative)	z (relative)	Azimuth (°)	Elevation (°)	Roll (°)
1	5.42	-1.11	-23.52				-178.99	0.62	3.85

	15.57	-0.93	-23.40	10.15	0.18	0.12	-179.99	1.18	3.76
2	5.45	-1.12	-23.53				177.27	1.04	2.65
	15.63	-1.29	-23.30	10.18	-0.16	0.22	177.93	1.35	1.32
3	5.35	-1.07	-22.89				-179.05	3.77	3.82
	15.43	-0.87	-21.77	10.08	0.21	1.13	177.11	5.25	1.84
4	29.66	-2.63	-21.68				179.17	0.34	1.43
	19.58	-2.66	-21.70	-10.08	-0.02	-0.02	176.19	0.06	-3.97
5	29.53	-3.78	-18.96				174.04	2.64	-5.20
	19.43	-3.70	-19.75	-10.10	0.08	-0.79	175.87	2.63	-8.32
6	29.61	-6.01	-20.61				174.26	-0.67	-6.17
	19.53	-5.86	-19.94	-10.08	0.15	0.67	176.95	-3.93	-5.91

Table A.3 the data measured for the calibration in X direction.

The mean of the 6 measurements was 10.11 cm, and the error here was 1.1%.

4.4.2. Calibration in y direction:

	X(cm)	**Y(cm)**	**Z(cm)**	**x (relative)**	**y (relative)**	**z (relative)**	**Azimuth (°)**	**Elevation (°)**	**Roll (°)**
1	2.44	3.63	24.42				139.17	5.09	6.15
	2.20	-6.28	24.66	-0.24	-9.91	0.24	141.59	-6.25	6.38
2	2.66	4.91	24.43				136.66	-5.13	5.68
	2.26	-4.99	24.65	-0.40	-9.90	0.22	141.42	-5.97	6.25
3	2.70	5.02	24.26				139.18	-4.90	4.62
	2.31	-4.87	24.38	-0.38	-9.89	0.12	140.75	-3.81	4.89
4	3.00	9.61	24.47				-143.71	-5.74	-5.70
	3.01	19.49	24.39	0.01	9.88	0.08	-143.63	-3.26	-3.86

5	2.94	10.79	24.34				-144.05	-4.39	-4.93
	3.00	20.76	24.34	0.05	9.98	0.00	-144.70	-3.34	-3.53
6	3.11	10.73	24.18				-144.06	-3.83	-4.19
	3.06	20.73	24.20	-0.04	10.00	0.01	-144.34	-2.38	-2.77

Table A.4 the data measured for the calibration in Y direction.

The mean of the 6 measurements was 9.92 cm, and the error here was 0.7%.

4.4.3. Calibration in z direction:

	X(cm)	Y(cm)	Z(cm)	x (relative)	y (relative)	z (relative)	Azimuth (°)	Elevation (°)	Roll (°)
1	2.79	9.16	12.42				-175.11	-3.51	-1.22
	4.46	9.04	22.30	1.66	-0.12	9.88	174.80	-5.98	1.77
2	2.14	9.39	12.14				-172.96	-2.62	0.59
	4.51	9.04	21.99	2.36	-0.35	9.85	-176.06	-8.94	-1.04
3	1.48	10.21	12.45				-170.89	-2.60	-0.98
	2.83	10.17	22.17	1.35	-0.05	9.72	-177.56	-3.79	3.23
4	10.25	-8.89	-8.76				179.98	-0.35	-1.24
	9.31	-8.64	-19.06	-0.95	0.25	-10.31	176.36	-5.37	3.45
5	10.17	-8.85	-9.10				179.68	0.87	3.25
	9.31	-8.72	-19.29	-0.86	0.13	-10.18	174.69	-9.28	-0.59
6	10.30	-8.73	-8.85				-175.27	-0.09	0.02
	9.43	-8.61	-19.10	-0.87	0.12	-10.25	-179.60	-5.88	-2.13

Table A.5 the data measured for the calibration in Z direction.

The mean of the 6 measurements was 10.03 cm, and the error here was 0.3%.

4.4.4. Calibration in azimuth angle:

	X(cm)	Y(cm)	Z(cm)	Azimuth (°)	Elevation (°)	Roll (°)
1	7.75	-10.47	-22.65	29.56	-1.61	1.07
2	7.75	-10.44	-22.55	29.90	-1.72	1.37
3	7.76	-10.45	-22.55	29.51	-1.75	1.22
4	7.42	-2.23	-22.76	-29.44	0.08	-3.30
5	7.51	-4.85	-22.73	-28.99	0.13	-2.72
6	7.53	-4.76	-22.71	-29.31	0.15	-2.64

Table A.6 the data measured for the calibration in Azimuth angle.

The mean of the 6 measurements was 29.45 degrees, and the error here was 1.8%.

4.4.5. Calibration in elevation angle:

	X(cm)	Y(cm)	Z(cm)	Azimuth (°)	Elevation (°)	Roll (°)
1	8.86	-6.84	-21.96	7.13	-29.69	-7.84
2	8.65	-6.33	-21.78	6.50	-29.43	-3.07
3	9.43	-6.50	-22.83	-4.51	-29.90	-1.12
4	1.24	-27.15	-8.82	-1.55	29.70	5.59
5	1.29	-26.92	-9.38	-1.02	31.33	1.00
6	1.13	-27.36	-8.77	-4.19	29.89	-0.35

Table A.7 the data measured for the calibration in Elevation angle.

The mean of the 3 measurements was 29.67 degrees, and the error here is 1.1%.

4.4.6. Calibration in roll angle:

	X(cm)	Y(cm)	Z(cm)	Azimuth (°)	Elevation (°)	Roll (°)
1	12.90	-4.42	-21.90	3.58	-2.46	30.27
2	12.79	-4.64	-22.08	-1.64	0.79	29.22
3	13.42	-3.76	-21.52	3.33	-2.16	29.97
4	12.04	-11.82	-22.41	-1.53	1.89	-29.92
5	12.01	-11.44	-22.43	0.96	6.63	-28.89
6	12.06	-11.79	-22.37	-0.89	2.45	-29.09

Table A.8 the data measured for the calibration in Roll angle.

The mean of the 6 measurements was 29.56 degrees, and the error here was 1.5%.

4.5. Conclusions:

The error of all the directions of the Polhemus tracker system was less than 2% and hence the apparatus is reliable.

Appendix B: the repeatability of having the same SPV in different trials of condition B in experiment 2.

There were 6 subjects who had participated two trials of the condition B of experiment 2 for the pilot study. The summary of EOG data for the two trails are shown in table B.1.

Subject number	Gender	Spv in 1st trail (dps)	Spv in 2nd trail (dps)	Difference (1st –2nd)
1	M	27.54	27.52	0.02
2	M	24.08	24.71	-0.64
3	F	26.91	27.55	-0.63
4	F	20.20	23.82	-3.62
5	M	30.11	29.23	0.88
6	M	28.07	25.93	2.15
Mean		26.15	26.46	-0.31

Table B.1 Summary of EOG data for the two trails of the pilot study

The statistical result for a paired T-test showed that there was no significant (p=0.917) difference between the SPVs in the two trials. So it can be said that the repeatability for subjects to have the same SPV in different trails is good. There is no evidence to say different trials would make different SPVs.

Appendix C: The shape effect of the moving fixation point in experiment 2

There were still 6 subjects participating in both two series of the condition C in the pilot study of experiment 2, with one condition using the cross as the moving eye-fixation point, the other condition using the square as the moving eye-fixation point. The summary of EOG data of those two series are shown in table C.1.

Subject number	Gender	SPV with cross point (dps)	SPV with square point (dps)	Difference (cross-square)
1	M	23.08	23.24	-0.17
2	M	16.43	15.54	0.89
3	F	23.44	22.10	1.34
4	F	21.56	24.36	-2.81
5	M	22.90	23.15	-0.25
6	M	20.69	20.96	-0.26
Mean		21.349	21.56	-0.21

Table C.1 Summary of EOG data of the two series of "third condition"

The statistical result for a Wilcoxon test showed that the difference in the SPVs between the two kinds of conditions weren't significant (p=0.735). Hence it can be said that changing from a square point into a cross point won't affect the SPVs of the subjects in the condition C of experiment 2.

Appendix D: Normality tests for the data in experiment 1 and 2

The results of the normality tests of the mean and median 7-point nausea data, vection rating data and the post SSQ data in experiment 1 are shown in table D.1. And the results of the normality tests for those variables in experiment 2 are shown in table D.2.

	condition	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
mean7nausea	1.00	0.19	16.00	0.14	0.91	16.00	0.11
	2.00	0.13	16.00	0.20*	0.94	16.00	0.41
	3.00	0.11	16.00	0.20*	0.95	16.00	0.57
	4.00	0.17	16.00	0.20*	0.90	16.00	0.08
median7nausea	1.00	0.19	16.00	0.12	0.87	16.00	0.03
	2.00	0.20	16.00	0.09	0.89	16.00	0.06
	3.00	0.14	16.00	0.20*	0.95	16.00	0.43
	4.00	0.16	16.00	0.20*	0.95	16.00	0.42
postSSQ	1.00	0.17	16.00	0.20*	0.93	16.00	0.22
	2.00	0.20	16.00	0.10	0.91	16.00	0.11
	3.00	0.24	16.00	0.01	0.87	16.00	0.03
	4.00	0.13	16.00	0.20*	0.94	16.00	0.31
vection	1.00	0.14	16.00	0.20*	0.97	16.00	0.80
	2.00	0.11	16.00	0.20*	0.95	16.00	0.46
	3.00	0.11	16.00	0.20*	0.96	16.00	0.72
	4.00	0.11	16.00	0.20*	0.97	16.00	0.81
* This is a lower bound of the true significance.							
a Lilliefors Significance Correction							

Table D.1 Tests of Normality for data in experiment 1

	condition	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
mean7nausea	1.00	0.20	15.00	0.10	0.90	15.00	0.08
	2.00	0.13	15.00	0.20*	0.96	15.00	0.62
	3.00	0.22	15.00	0.05	0.91	15.00	0.12
median7nausea	1.00	0.17	15.00	0.20*	0.91	15.00	0.13
	2.00	0.19	15.00	0.14	0.94	15.00	0.38
	3.00	0.20	15.00	0.09	0.91	15.00	0.16
postSSQ	1.00	0.32	15.00	0.00	0.70	15.00	0.00
	2.00	0.19	15.00	0.15	0.93	15.00	0.32
	3.00	0.14	15.00	0.20*	0.95	15.00	0.51

vection	1.00	0.19	15.00	0.17	0.88	15.00	0.05
	2.00	0.19	15.00	0.17	0.89	15.00	0.07
	3.00	0.15	15.00	0.20*	0.96	15.00	0.76
* This is a lower bound of the true significance.							
a Lilliefors Significance Correction							

Table D.2 Tests of Normality for data in experiment 2