

Chapter 3. Apparatus and experimental procedure

3.1 Introduction

This chapter describes the apparatus used in the experimental work presented later in the thesis, including the optokinetic drum and virtual reality apparatus used to display moving images to subjects. Other experimental procedure is also described.

3.2 Moving image systems

3.2.1 The optokinetic drum

The optokinetic drum was a cylinder of 1m diameter and 1.2m high supported by a steel frame and counter-balanced by a 90 kg weight. The inside of the drum was covered with alternate black and white stripes each subtending approximately 8° at the subject's eyes. The drum was lit by a 12V, 20W halogen bulb, located at the centre of the drum 20cm below the roof of the drum. The seat of the drum could be raised or lowered in order to ensure that subjects were level with the centre of the drum.

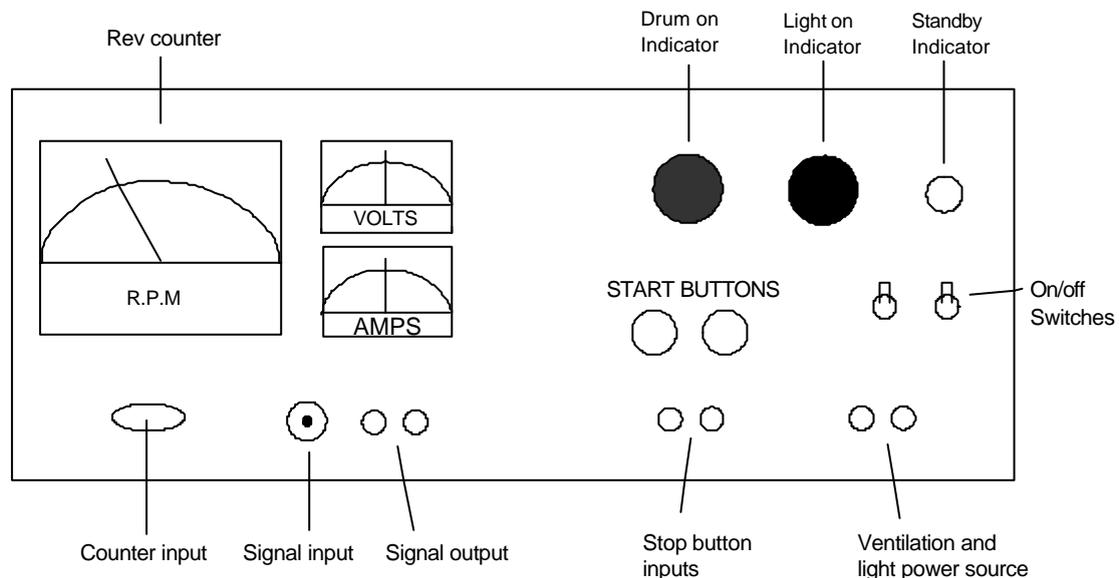


Figure 3.1. The optokinetic drum control box.

3.2.1.1 The drum controls

The optokinetic drum was controlled by a unit specially built in the Human Factors Research Unit. This allowed control over the speed of the drum and also contained two safety features to ensure that accidental operation was not possible and that the drum could be stopped quickly when desired (i) The drum could only be started by pressing two buttons simultaneously (see Figure 3.1) (ii) both the experimenter and subject had an emergency stop button which immediately halted the drum, if pressed. Motion input to the drum was from a standard signal generator, which was used to generate a constant speed of drum rotation in the clockwise direction (as seen from above) for the three occasions when the drum was used in this thesis, but could be used to create sinusoidal motion if necessary.



Figure 3.2. A subject shown sitting in the optokinetic drum seat. The drum is in the raised position to allow access to the seat. The head restraint is not shown.

3.2.1.2 Seating

The seat was situated so that the subject's head was situated at the centre of the drum. The wooden backrest was 1.2 m high and had three slits cut into it – one in the centre of the backrest and two 15cm on each side of the centre slit. The two slits on each side allowed a strap to be placed around the head of a subject to minimise head movements in the drum. A subject is shown in the seat of the drum, with the drum in the raised position in Figure 3.2.

3.2.1.3 Ventilation

The drum contained a ventilation system consisting of a 12W fan and a ventilation tube which drew air into the drum from the room in which the drum was situated. The tube was fixed to the back of the seat backrest so that the end of the tube was level with the top of the seat. Drum temperature typically varied by 1° during the course of an experiment when using the ventilation compared to a variation of 3-4° without the ventilation (Holmes, 1998).

3.2.1.4 Monitoring

It was possible to monitor subjects inside the drum by placing a small video camera on the floor, pointing up into the drum and relaying images to a video screen outside the drum. In this way it was possible to ensure that subjects had their eyes open during exposure.

3.2.1.5 Luminance and contrast of the stripes

The luminance of the stripes with the optokinetic drum in its down position was measured using a Minolta luminance meter. The luminance of the black stripes was 1.44 candelas/m². The luminance of the white stripes was 31.28 candelas/m².

There are many different ways to express contrast. The following are two of the common ways. It is possible to use the above luminance values to calculate any other measure of contrast if necessary. The contrast ratio (maximum luminance divided by minimum luminance) was 21.72. Modulation contrast (or Michelson contrast) was 0.91 (max – min / max + min).

3.2.2 The virtual reality system

This consisted of a Virtual Research VR4 head mounted display. This model displayed moving images that were the same as that seen on a computer monitor by sampling the image sent to the monitor (Deltascan pro system). Full screen Microsoft AVI video files could be displayed on the computer using Windows Media Player and hence also seen by the subject on the virtual reality display. The same images were always presented monocularly, that is the same image was seen by each eye simultaneously. Figure 3.4 shows a diagram of the connections between computer and the virtual reality system.



Figure 3.3. The virtual reality headset (Virtual Research VR4).

The VR4 headset had a field of view of 48° horizontally by 36° vertically and a focal point of approximately one metre. The distance between two eye-pieces could be adjusted by the subject to match their inter-pupillary distance. The Virtual Research VR4 head-mounted display is shown in

Figure 3.3.

Video file production was carried out using Kinetix' 3D Studio MAX software version 1.2. This software allowed video files to be created of any object with any material, texture or colour applied to the object. In the case of creating a simulation of an optokinetic drum, a cylinder was created with a black and white striped texture applied. A 'virtual' camera was placed at the centre of the drum and a series of key-frames were created with the drum at different angular positions. The video file was created automatically by the software, where each frame was calculated with reference to the key-frames (i.e. the position of the drum at each frame was extrapolated from the key frames). The result was a video file of moving black and white stripes as would be seen in a real optokinetic drum. The video files were all

created at 60 frames per second. The video files were played back to subjects monocularly (both eyes saw the same image sequence) on the Virtual Research VR4 virtual reality head mounted display. The advantage of playing back pre-prepared video files was that the experimenter could control exactly what was seen by subjects

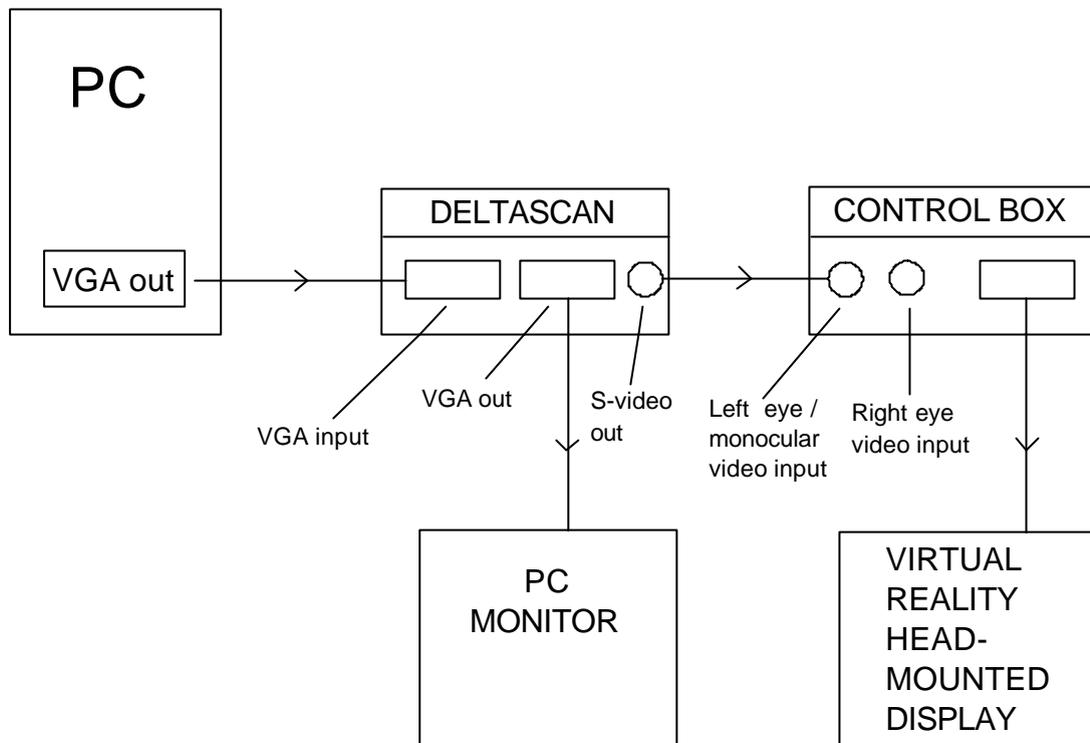


Figure 3.4. Diagram of the connections between the computer (PC), Deltascan (video signal sampler), the virtual reality head-mounted display and computer monitor. The Deltascan system samples the video output from the PC and sends copies to the computer monitor and the virtual reality system.

and there were no problems associated with virtual reality displays such as time lags in the updating of images where head movements are made.

3.2.3 Luminance and contrast of the stripes

In the virtual reality simulations of the optokinetic drum, the luminance of the black stripes was 1.65 candelas/m² and the luminance of the white stripes was 30.53 candelas/m². The contrast ratio was 18.5 and the modulation contrast (Michelson contrast) was 0.90. Luminance was measured by focusing the Minolta luminance meter through the eyepiece of the virtual reality head-mounted display. For the purposes of the measurement the whole screen was either filled a single black or white stripe to ensure that the luminance meter was focusing on the correct colour.

3.3 Vision testing equipment

Vision tests were completed using two pieces of equipment (i) Keystone visual skills profiles (ii) The Arden test of contrast sensitivity.

3.3.1 Keystone visual skills profiles

This equipment allowed a variety of visual tests to be performed on subjects at two viewing distances, 0.4 metres (2.5 dioptres – ‘the near point’) and 4 metres (0.25 dioptres – ‘the far point’). The tests consisted of various cards which were inserted into the card holder individually. The tests used included tests of simultaneous perception (to determine whether both eyes are used at the same time), vertical and horizontal muscle balance tests, which indicated whether there was a tendency for one eye to drift higher than the other (vertical hyperphoria), for the eyes to cross (esophoria) or to not converge at the correct distance (exophoria). There were also tests of colour perception, to indicate the presence of colour blindness and tests of visual acuity, which used the Landolt broken ring test. The visual acuity tests were performed binocularly and with each eye separately.

Separate testing cards were used for the near and far points. Figure 3.5 shows a subject using the Keystone system, set at the far point.



Figure 3.5. A subject undergoing vision tests with the Keystone visual skills profiles testing equipment. Card holder is set to the ‘far point’. The holder can be moved towards the subject to the ‘near point’.

3.3.2 The Arden test of contrast sensitivity

A test known as the “Arden Test” was used in order to obtain information about the contrast sensitivity of subjects to a broad range of spatial frequencies, not just sensitivity to high spatial frequencies at maximum contrast, as measured by the visual acuity tests used in the Keystone visual skills profiles.

In the Arden test, a card was slowly removed from a holder. Each card had a sinusoidal variation across the card of grey to black. The contrast increased as the card was removed from a holder, up until the point at which a subject could see the difference in contrast (i.e. the card no longer looked grey all over). At the point at which the card was stopped, a number was read off the edge of the card to indicate the contrast sensitivity to that particular spatial frequency. The spatial frequencies used were 0.3, 0.6, 1.25, 2.5, 5 and 10 cycles per degree, when viewed at 0.50 metres, as per the Arden test instructions. An example of a card is shown in Figure 3.6.



Figure 3.6. The Arden test of contrast sensitivity – demonstration plate used to demonstrate the test to subjects. The difference in contrast is exaggerated on this demonstration card.

3.4 Eye movement measurements

3.4.1 Electro-oculography measurements

Eye movements were recorded in experiments 2 and 4 (Chapters 5 and 7) by the means of electro-oculography. The connections between the equipment used are shown in Figure 3.7. Three disposable electrodes were attached to each subject, the positions of which are shown in Figure 3.8. The signal from the electrodes was sent to a device called the 'Hortmann electro-nystagmograph' which was used to amplify the signal. The amplified signal was then sent to an *HVLab* data acquisition computer

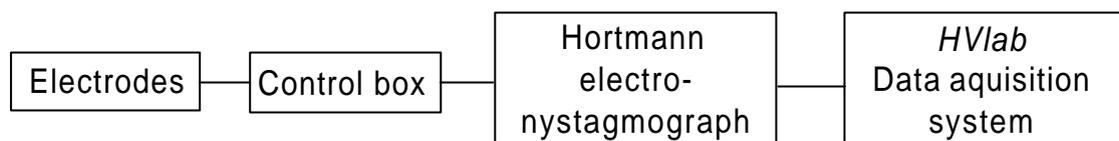


Figure 3.7. Diagram to show the connections of equipment for electro-oculography measurements. Eye displacement data was sampled at 30 samples per second, with a low pass filter at 10Hz.

(built at the Human Factors Research Unit at the University of Southampton) which digitally sampled the signal at a rate of 30 samples per second with a low pass filter at 10Hz. Each signal could be viewed and analysed using the *HVLab* software. The accuracy of electro-oculography recordings is in the region of 0.5-1.0 degree of visual angle (Hallett, 1976).

Eye movements were calibrated by asking subjects to look at 3 crosses marked horizontally on a wall in front of them. The first cross was directly in front of the

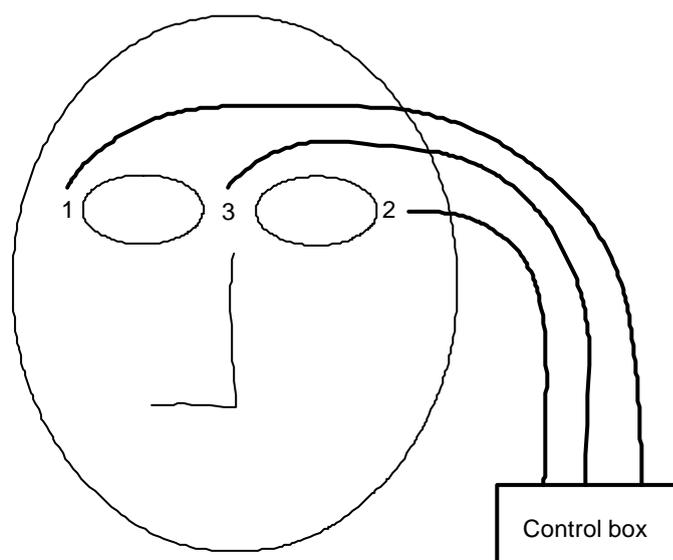


Figure 3.8. Shows the position of the electrodes on a subject for the electro-oculography measurements.

subject (between the two eyes) and the other crosses were at 15° visual angle symmetrically either side. Subjects made eye movements between the crosses at the verbal request of the experimenter. The calibrations were also recorded to the *HVLab* data acquisition system.

3.4.2 Infra-red light eye movement measurement (IRIS)

The final experiment of this thesis, presented in Chapter 9, required a more accurate measurement of eye movements than those which could be achieved with standard electro-oculography measurement techniques. The experiment used a system from the company 'Skalar Medical' called IRIS (infra-red light eye-movement measurement) which has a measurement range of 25° horizontally and 20° vertically, with an accuracy of 1 minute of visual arc (Reulen *et al.*, 1988). The system consisted of an emitter and sensor which are positioned in front of the eye (Figure 3.10 shows the sensor placement). The varying reflection of the eye, as it moves, is detected by the sensor and an output voltage proportional to displacement of the eye is generated. A subject wearing the measurement device is shown in Figure 3.13, front and rear panel controls are shown in Figure 3.11 and 3.12.

The output from the IRIS system was sent to an *HVLab* computer system and the displacement signals for the left and right eyes were sampled at a rate of 300 samples per second, with a low-pass filter cut-off at 100Hz. The equipment connections are shown in Figure 3.9.



Figure 3.9. The equipment connections for the IRIS system. Eye displacement data was sampled at 300 samples per second, with a low pass filter at 100Hz.

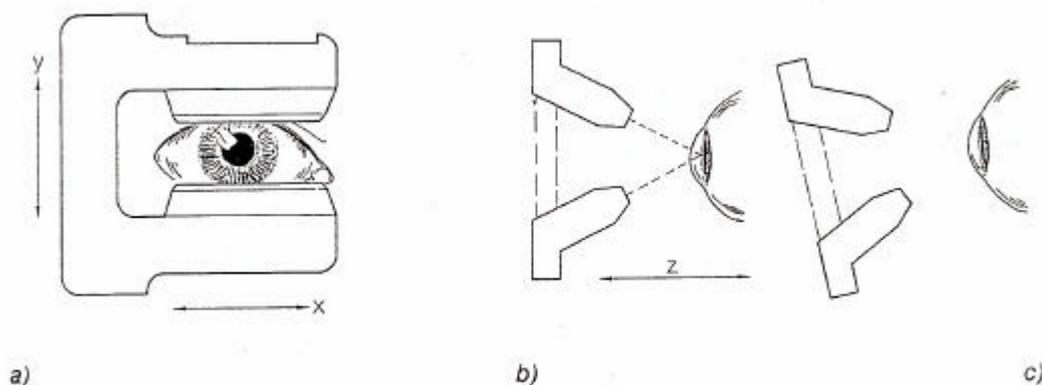


Figure 3.10. Horizontal sensor adjustment. (a) front view (b) side view (c) alternative adjustment.

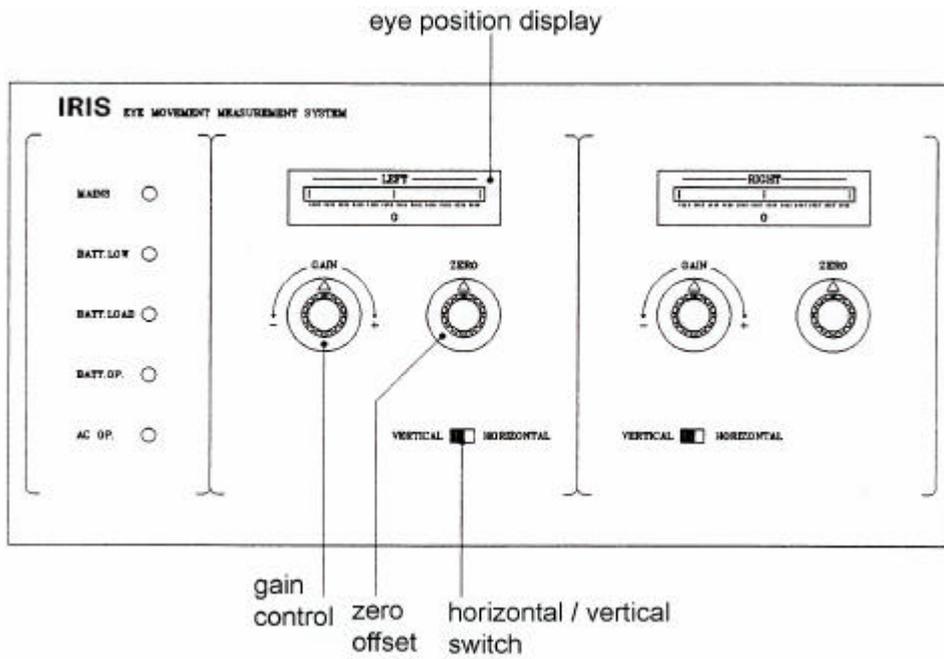


Figure 3.11. The front panel controls of the IRIS system.

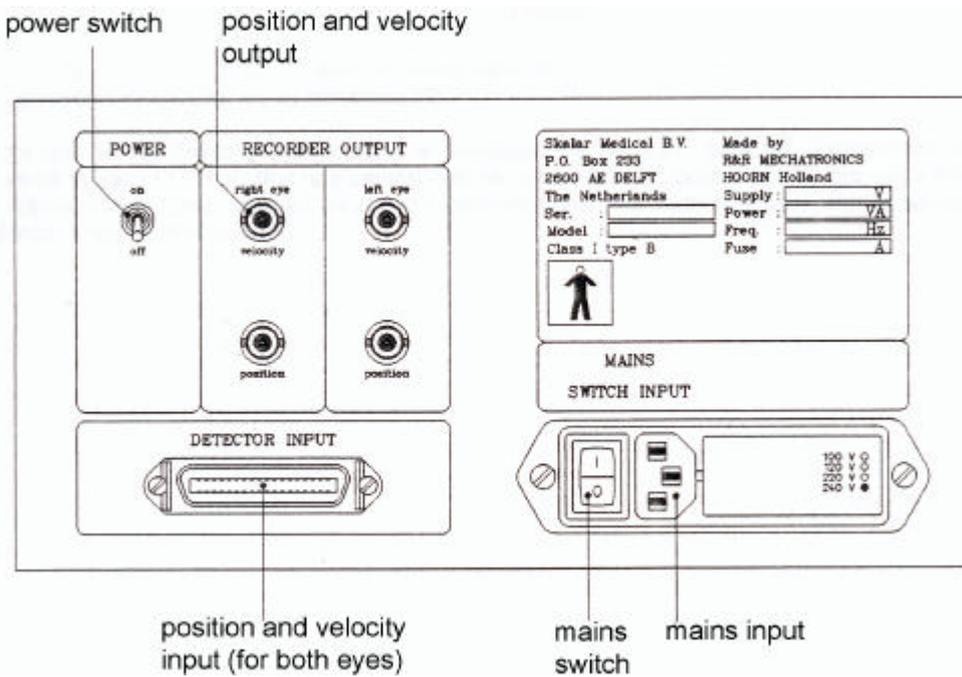


Figure 3.12. The rear panel controls of the IRIS system.



Figure 3.13. A subject shown wearing the IRIS eye position sensors.

3.5 Other experimental procedure

This section gives details on the subjective scales which were used in the experimental work for subjects to report their symptoms of motion sickness, their perception of self-motion (vection), the questionnaires used to rate their post-exposure symptoms and the questionnaire to measure their previous susceptibility to motion sickness in standard forms of transport (e.g. cars, buses, ships).

3.5.1 The subjective motion sickness rating scale

During each of the experiments presented in the later chapters of the thesis subjects reported a number from the subjective rating scale in Table 3.1 to indicate their subjective symptoms of motion sickness at that time. The scale is based on a scale by Golding and Kerguelen (1992). Since motion sickness symptoms do not necessarily occur in any particular order subjects were able to report any number on the scale at any time. Accumulated illness ratings were calculated, after exposure, by summing the motion sickness ratings reported each minute.

Table 3.1. The subjective motion sickness rating scale. (Golding and Kerguelen, 1992). Subjects report a number each minute for the duration of the exposure.

Subjective Response	Corresponding Feeling
0	No symptoms
1	Any symptom, however slight
2	Mild symptoms e.g. stomach awareness, but no nausea
3	Mild nausea
4	Mild to moderate nausea
5	Moderate nausea, but can continue
6	Moderate nausea, want to stop

3.5.2 Subjective vection rating scales

The scale shown in Table 3.2 was used to record subjective self-motion ratings each minute. The scale was designed to indicate common perceptions of self-motion, such as whether a subject felt like the optokinetic drum was the only thing moving, whether the subject felt like the drum was moving and also experienced self motion intermittently, continuously or whether the subject perceived continuous self-motion whilst perceiving a stationary optokinetic drum. Accumulated vection scores were calculated by assigning a value of 0 to 'Drum only', 1 to 'Drum and self, intermittent', 2 to 'Drum and self, continuous' and 3 to 'Self only'.

Table 3.2. Subjective vection rating scale. Subjects reported one of the following options each minute for the duration of the exposure.

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

The subjective vection rating scale was used in the first three experiments presented in this thesis (Chapters 4 to 6). It was used for both the real optokinetic drum and for simulated optokinetic drums presented on the VR4 virtual reality head-mounted display.

In the fourth experiment an optokinetic drum simulation was not used, so a different vection rating scale was created. Shown in Table 3.3, this scale was a percentage scale where 0% indicated no vection (i.e. only the visual stimulus was perceived to be moving). An increasing percentage score indicated increased vection, for example 50% indicated that the subject perceived the stimulus and themselves to be moving at approximately the same speed (in opposing directions). 100% indicated that the subject felt that they were moving and the visual stimulus was stationary. Subjects could report any number between 0 and 100% at each measurement, made each minute. An average percentage score was calculated for each subject from the individual percentage vection scores.

3.5.3 Motion sickness history questionnaire

Before commencing an experiment, subjects were asked to complete a motion sickness history questionnaire (Griffin and Howarth, 2000) to indicate their previous susceptibility to motion sickness caused by the common forms of transport. The

Table 3.3. Vection scale for experiments 4 to 6. Subjects report a percentage score between 0 and 100% each minute to indicate their perception of self motion.

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

questionnaire allows values to be calculated for susceptibility in the previous year ($I_{\text{susc. (yr.)}}$), total susceptibility in all previous years (M_{total}) or, if necessary, susceptibility to land or non-land transport could be calculated separately. The full questionnaire is shown in an Appendix of this thesis.

3.5.4 Post-exposure rating scale

After exposure, subjects were asked to complete a post-exposure symptoms questionnaire to indicate the symptoms which they had experienced at any time during the exposure to the moving stimulus. This post-exposure scale was used in the first five experiments (Chapters 4 to 8). Subjects were asked to fill in the questionnaire by ticking a response for each symptom of 'none', 'slight', 'moderate' or 'severe'. The symptoms 'difficulty focusing' and 'blurred vision' were removed from the questionnaire in the third experiment (Chapter 6) where an artificially blurred stimulus was presented to subjects in one condition. A score for each symptom was calculated for each subject by allocating a score of 0 for 'no symptoms', 1 for 'slight symptoms', 2 for 'moderate symptoms' and 3 for 'severe symptoms'. The individual values for each symptom were summed to give a total post-exposure symptom score.

Table 3.4. The post-exposure symptom questionnaire.

Symptom	None	Slight	Moderate	Severe
General Discomfort				
Fatigue				
Headache				
Eye Strain				
Difficulty Focusing				
Increased Salivation				
Increased Sweating				
Nausea				
Difficulty Concentrating				
Blurred Vision				
Dizziness				
Stomach Awareness				
Burping				