Chapter 8. Comparison of motion sickness with and without vision correction

8.1 Introduction

The previous experiments have shown a possible influence of visual acuity on motion sickness survival time, with poorer acuity being associated with shorter survival times. The model shown at the end of Chapter 7 shows the hypothesis that visual acuity and possibly artificial blur, act to influence the pursuit component of the slow phase of nystagmus. It was necessary to understand more about the influence of visual acuity, for instance whether it is only poor sensitivity to high spatial frequencies at high contrast (as measured by the Landolt broken ring test) which influence motion sickness, or whether it is an effect which occurs across a broad range of spatial frequencies at varying contrast. Subjects were tested with and without their corrective spectacles or contact lenses and completed contrast sensitivity tests, to measure their contrast sensitivity at a range of spatial frequencies, in addition to the standard vision tests used previously.

By studying the model (Chapter 7), it was hypothesised that only sensitivity to high spatial frequencies would be correlated to motion sickness incidence because of the proposed influence of the fovea, which is responsible for detection of high spatial frequencies, on eye movements. It was also predicted that subjects without their vision correction would experience greater motion sickness symptoms. Vection was predicted to be similar in the two conditions.

8.2 Method

8.2.1 Pre – exposure tests

Twenty subjects aged 18 to 33 years were selected on the basis that they wore spectacles or contact lenses in everyday life. The visual tests were administered as in all the previous experiments. An additional test was performed: the ‘Arden’ test of contrast sensitivity (Skalka, 1981). The test was performed at a distance of 0.5m with each eye measured separately, at each frequency. The test consisted of cards with vertical bar gratings whose darkness varied sinusoidally from grey to darker grey (see Figure 8.1), with the contrast between the darkest and lightest areas increasing along the vertical length of the card. As the card was withdrawn from a holder, the

difference in contrast gradually became more discernible. The experimenter exposed the card and the subject indicated to the experimenter when it was possible to see the difference in contrast (i.e. it no longer looked all one shade of grey). A number was read from the card at that point to give a score. The maximum score was 20. If a subject did not see the contrast at 20 (with the full card exposed) then the arbitrary figure of 25 was assigned as the score for that card, as per the Arden test instructions. Each successive card had a higher spatial frequency. The six spatial frequencies tested were 0.3, 0.6, 1.25, 2.5, 5 and 10 cycles / degree.

Figure 8.1. Arden test of contrast sensitivity.

All tests were performed with and without visual correction (i.e. spectacles or contact lenses). Subjects were asked to provide a copy of the prescription for their spectacles or contact lenses. They also completed the motion sickness history questionnaire.

8.2.2 Exposure sessions

Two exposure sessions consisted of 20 minutes in the optokinetic drum rotating clockwise at 5 r.p.m. Subjects viewed the drum with vision correction for one session and without vision correction for another session. The two sessions were at least two weeks apart to help minimise any habituation effects. Ten subjects commenced by viewing without vision correction and the other 10 commenced viewing with vision correction.

Subjects reported motion sickness scores as in all previous experiments and vection scores on the percentage scale as used in Experiment 4 (Table 7.1). During the exposure period, subjects were viewed on a video monitor to ensure that they had their eyes open and were looking straight ahead. Immediately after exposure, subjects completed a post exposure symptoms questionnaire to indicate symptoms experienced during exposure.

8.3 Analysis

Average vection and accumulated illness ratings were calculated as previously. Motion sickness, vection scores across conditions and comparisons of visual acuity across conditions were analysed using the Wilcoxon matched-pairs signed ranks test. Spearman's rank correlation test was used to test the relationships between vection and motion sickness in conditions. Survival analysis was performed as in previous experiments, with the addition of the contrast sensitivity scores.

8.4 Results

8.4.1 Contrast sensitivity vs. visual acuity

Subject visual acuity at the near point was significantly different with and without vision correction (Wilcoxon, $p<0.000$) (i.e. all subjects had poorer acuity at the near point without correction). Contrast sensitivity scores were significantly different with and without vision correction (Wilcoxon, $p<0.01$) with the exception of the lowest measured frequency of 0.3 cycles per degree, which was marginally significantly different (Wilcoxon, $p<0.10$).

Correlations between visual acuity and contrast sensitivity at the different spatial frequencies *without correction* were increasingly significant with increasing spatial frequency. The correlations are shown in Table 8.1. Correlations are negative because a high score on the Arden contrast sensitivity test corresponds to poor vision, whereas a high score on the acuity test corresponds to good vision.

The contrast sensitivity scores *with* correction did not correlate with visual acuity – possibly because there was very little variation in the visual acuity scores with correction. Only one subject had worse than 20:20 vision with correction.

Table 8.1. Correlations between Landolt acuity and contrast sensitivity scores at varying spatial frequency, without vision correction.

Spatial frequency (cycles per degree)	Correlation with visual acuity (as measured by the Landolt broken ring test)
0.30	ρ= -0.172, *p* = 0.468
0.60	ρ= -0.573, *p* = 0.008
1.25	ρ= -0.703, *p* = 0.001
2.50	ρ= -0.672, *p* = 0.001
5.00	ρ= -0.692, *p* = 0.001
10.0	ρ= -0.766, *p* = 0.000

8.4.2 Motion sickness

The accumulated illness ratings were significantly higher when subjects did not wear their spectacles – a mean of 35.1 without correction and 21.5 with correction

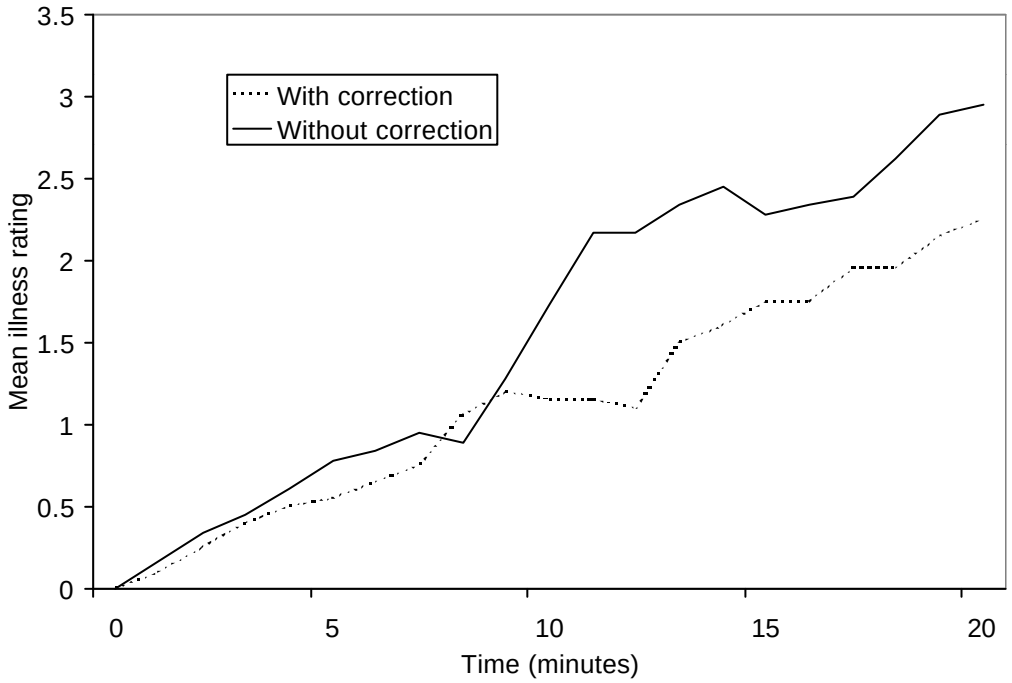

Figure 8.2. Mean illness ratings against time for both conditions.

(Wilcoxon, $p<0.05$). Post exposure symptoms were significantly higher when subjects did not wear spectacles (Wilcoxon, $p<0.05$). Motion sickness scores across the two conditions were significantly correlated ($\rho=0.650$, $p<0.01$). Motion sickness scores

were not correlated with vection scores in either the corrected vision (ρ=-0.114, p>0.10) or in the uncorrected vision condition (ρ=-0.004, p>0.10). Figure 8.2 shows the mean illness ratings against time for the two conditions.

8.4.3 Vection

There was no difference in the vection scores for the two conditions (Wilcoxon, p>0.10). Vection scores across the two conditions were significantly correlated (ρ= 0.623, p<0.01).

8.4.4 Survival analysis – uncorrected vision

In the uncorrected vision condition, subject visual acuity scores at the near point were correlated with survival time for the uncorrected vision condition (ρ= 0.480, p<0.05). As found previously, subjects had lower survival times if they had lower acuity. Subject scores for the two lowest frequencies of contrast sensitivity (0.3 and

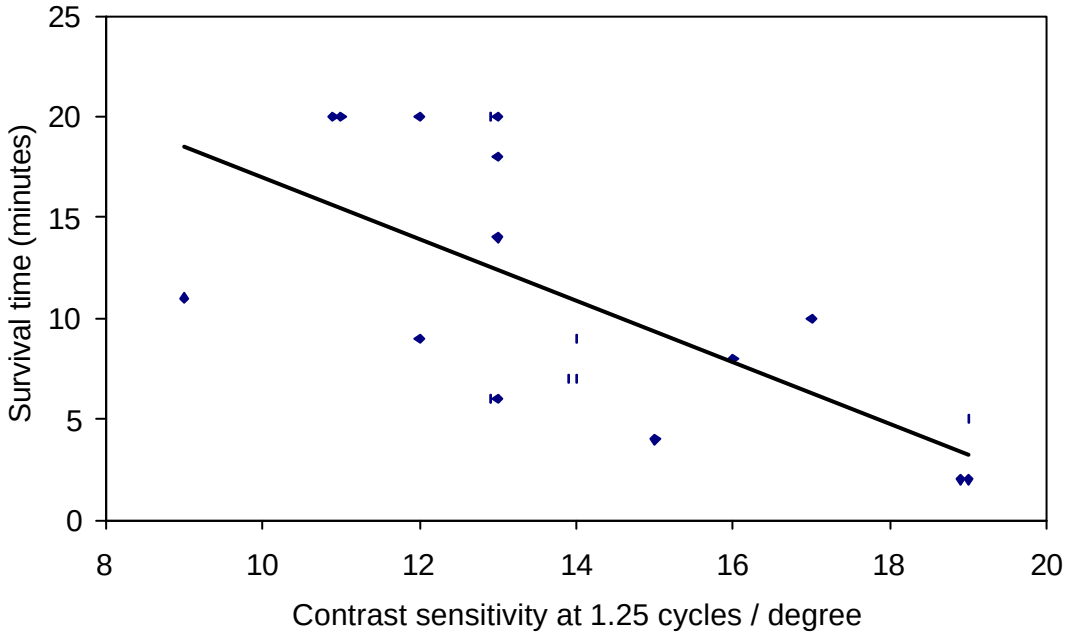

Figure 8.3. Survival times for various subject acuity scores at the 1.25 cycles per degree spatial frequency. Uncorrected vision condition.

0.6 cycles/°) were not correlated with motion sickness but the scores at the four highest spatial frequencies were either significantly correlated or there was a marginally significant correlation (the correlations are shown in Table 8.2.).

With each of the spatial frequencies those subjects with poorer contrast sensitivity had lower survival times. With the exception of the 1.25 cycles/° spatial frequency, the correlations become stronger with increasing spatial frequency. The contrast sensitivity score at the spatial frequency of 1.25 cycles/° was correlated very strongly with motion sickness survival time, see Figure 8.3.

Table 8.2. Correlations between contrast sensitivity scores and time taken to reach number 2 on the motion sickness scale for the uncorrected vision condition.

Spatial frequency (cycles per degree)	Correlation
0.30	ρ = -0.158 p = 0.507
0.60	ρ = -0.324 p = 0.164
1.25	ρ = -0.726 p = 0.000
2.50	ρ = -0.418 p = 0.067
5.00	ρ = -0.423 p = 0.063
10.0	ρ = -0.560 p = 0.010

8.4.5 Survival analysis – corrected vision

In the corrected condition, visual acuity at the near point was not correlated with motion sickness (ρ=0.298, p>0.10), however there was a much smaller range of visual acuity scores with corrected vision (only one subject had a score of lower than 20:20 with correction). There were no significant correlations between survival times and contrast sensitivity scores (the statistics are shown in Table 8.3). Motion sickness susceptibility ratings derived from the history questionnaire were marginally significantly correlated with motion sickness survival times (ρ=-0.381 p<0.10).

Table 8.3. Correlations between contrast sensitivity scores and time taken to reach number 2 on the motion sickness scale for the corrected vision condition.

Spatial frequency (cycles per degree)	Correlation with survival time (corrected vision condition)
0.30	$\rho = -0.187$ $p = 0.430$
0.60	$\rho = -0.133$ $p = 0.576$
1.25	$\rho = -0.021$ $p = 0.929$
2.50	$\rho = -0.043$ $p = 0.858$
5.00	$\rho = -0.002$ $p = 0.994$
10.0	$\rho = -0.094$ $p = 0.693$

8.4.6 Cox's proportional hazards model

For the uncorrected vision condition, the visual acuity data and contrast sensitivity variables, at 1.25 and 10 cycles per degree, were added into a Cox regression model. It was found that the contrast sensitivity score recorded at 1.25 was significantly influencing survival time, with poorer vision resulting in a decreased survival time, as expected. The visual acuity at the near point and the contrast sensitivity at 10 cycles / degree were not found to be significant influences in this Cox regression model when included with the contrast sensitivity data at 1.25 cycles / degree, although were significant when included individually. This indicates that, of the three variables, the contrast sensitivity score at 1.25 cycles per degree was the most significant influence on survival time. The Cox's proportional hazards model is shown in Table 8.4.

In the corrected vision condition, the marginally significant correlation between past susceptibility and survival time, was investigated with a Cox regression model. No influence of past susceptibility was found on survival time by the Cox regression model. The data are shown in Table 8.4.

Table 8.4. Cox's proportional hazards model for both conditions.

Condition	Independent variables	e^b	Sig (b)
Uncorrected vision	Contrast sensitivity at 2.5 cycles per degree	1.518	0.0008
Corrected vision	Past susceptibility	1.0275	0.1775

8.5 Discussion

8.5.1 Corrected vs. uncorrected vision

Motion sickness was significantly higher in the condition without vision correction as expected from the previous experiments and model. Vection was no different between conditions and the vection scores were uncorrelated with motion sickness scores, again as expected from the model. The influence of visual acuity on motion sickness was found in the uncorrected vision condition where there was a wide range of acuity scores. It was not found in the corrected vision condition, probably due to the small variation in acuity (all the subjects, with the exception of one, had better than 20:20 vision).

8.5.2 Contrast sensitivity vs. visual acuity

There were correlations found between the Landolt measure of visual acuity and contrast sensitivity at all but the lowest spatial frequency. This was only the case in the uncorrected vision condition, where the majority of subjects had visual acuity scores in the range of 20:200 (low) to 20:30 (high), which correspond to spatial frequency limits of 6 cycles per degree to 40 cycles per degree. The increasingly significant correlations between visual acuity and contrast sensitivity at the higher spatial frequencies measured (i.e. 5-10 cycles per degree) may possibly occur because these higher frequencies fall within the range of 6-40 cycles per degree, i.e. the upper limit of visual acuity measured for these particular subjects.

In the case of visual acuity measured with corrected vision, the high scores in the visual acuity test, where 20:20 vision corresponds to a spatial frequency of 60 cycles per degree (i.e. 1 minute of visual arc) may not have been expected to correlate with the low and medium spatial frequency scores.

8.5.3 Contrast sensitivity and motion sickness survival.

Generally the higher contrast sensitivity scores were more highly correlated with motion sickness survival time than the low frequency scores. The two lowest frequencies (0.3 and 0.6 cycles per degree) were not significantly correlated. The higher frequencies were all correlated or marginally correlated with survival time. Correlation coefficients increased with spatial frequency, with the exception of the 1.25 cycles per degree spatial frequency where a highly significant correlation was found between survival time and visual acuity at that frequency (ρ=0.726, p<0.000). Whether this is a chance result, or a more significant finding is not known at this stage.

8.5.4 The effect of spectacle magnification on motion sickness

There were 17 subjects (out of the total of 20) who wore spectacles in this experiment, whilst the remaining 3 wore contact lenses. Spectacles have the effect of either minimising or magnifying the image seen through them. This does not occur with contact lenses because they fit directly onto the eye. A possible reason for the difference in motion sickness between the two conditions could be the difference in image magnification or minification. However, in the uncorrected vision condition, all subjects viewed the optokinetic drum without vision correction. The heads of subjects were restrained in all conditions, so the vestibulo-ocular reflex response was not activated. In this condition, visual acuity and contrast sensitivity scores were correlated with motion sickness survival time. This suggests that the effect of visual acuity and contrast sensitivity to the higher spatial frequencies occur independently of a possible separate effect of image magnification.

8.6 Conclusion and updated model

It may be concluded that the influence of vision on motion sickness is based mainly on lack of sensitivity to medium to high spatial frequencies (i.e. poor resolution of fine images on the fovea). The result from Experiment 3 (Chapter 6) where an increase in post exposure symptoms were found with artificial blurring of the stimulus, is consistent with the result from this experiment (i.e. that motion sickness survival is mostly correlated with lack of sensitivity to higher spatial frequencies, which are missing with poor acuity, and were artificially removed by blurring).

8.6.1 Updated model

The model has been updated in a simple way by simply adding ‘low pass filter’ symbols to the ‘acuity’ and ‘blur’ inputs to indicate that these are both methods of reducing the high frequency information available on the fovea, which in turn may be responsible for the influence on motion sickness. The model is presented in Figure 8.4.

The reason for the increase in motion sickness with poorer contrast sensitivity to high spatial frequencies is not known, although the model suggests a hypothesis: that reduced sensitivity to high spatial frequencies may reduce the influence of the fovea on the control of the slow phase of nystagmus. Nystagmus gain has been shown to be lower with reduced input from the fovea (see Section 2.3.7.2 for a full review), so in the case of poor contrast sensitivity to high spatial frequencies, the gain of the slow phase of eye movements may be lower. If this is the case then the velocity of image slip on the fovea (and peripheral retina) will be greater with poorer visual acuity. In the model, two inputs to motion sickness still remain: (i) via foveal image slip (ii) via eye movements. The 6th and final experiment, presented in the next chapter addresses the possibility that eye movements may vary with visual acuity and contrast sensitivity to high spatial frequencies.

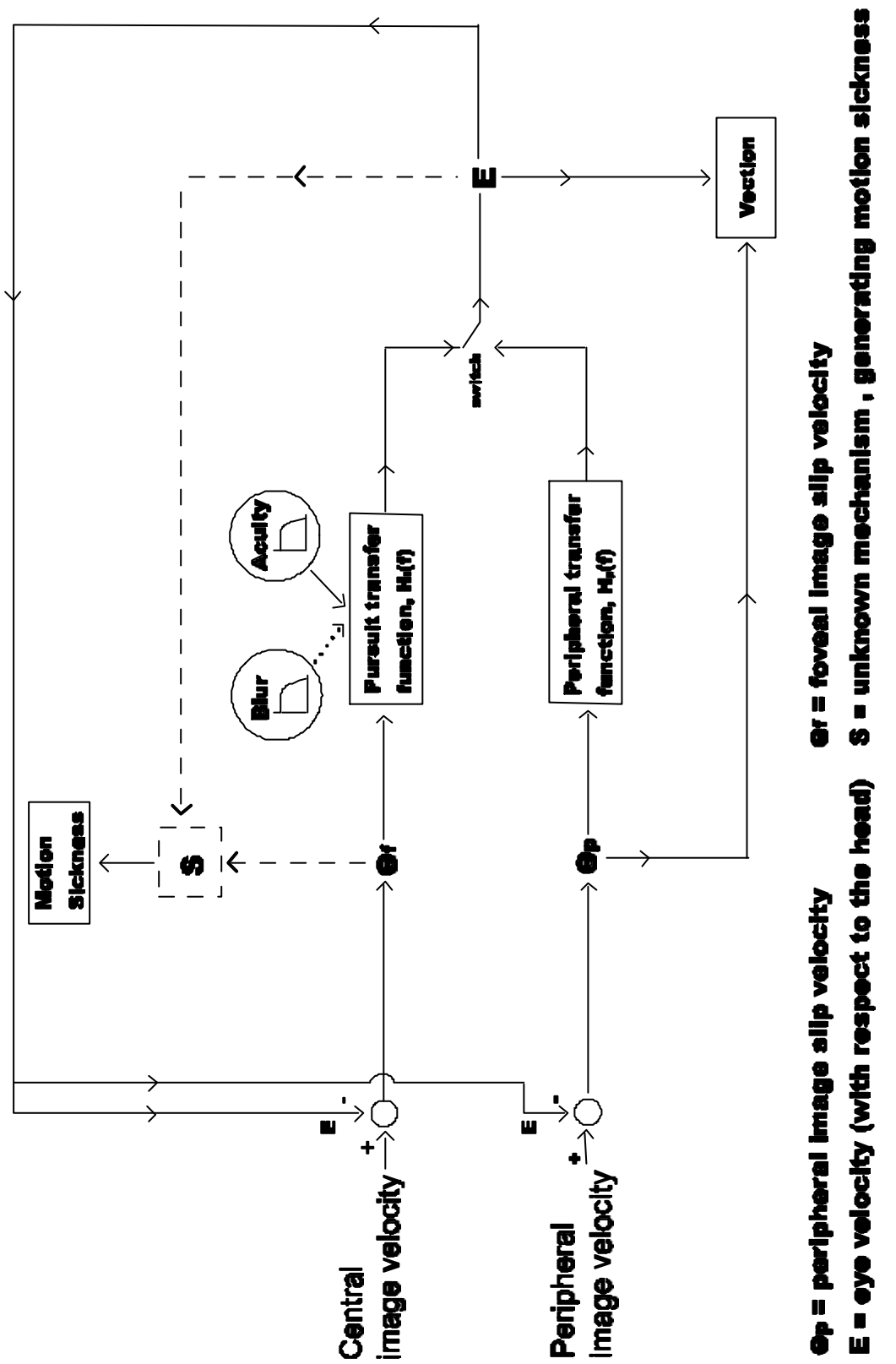

Figure 8.4. Model version 4. Taking into account the correlation between contrast sensitivity to high spatial frequencies and motion sickness.