Comparison of the slow phase velocity of nystagmus with and without vision correction

Introduction

The final experiment of this thesis aimed to test the hypothesis that visual acuity or contrast sensitivity can influence the slow phase velocity of nystagmus in response to motion of an optokinetic drum. Eye movements were recorded with an accuracy of 1 minute of visual angle (Reulen *et al.,* 1988), using an infra-red corneal reflection system (IRIS), with and without vision correction.

Method

Pre–exposure tests

Thirteen male subjects, aged 18-25, were selected on the basis that they wore spectacles or contact lenses in everyday life. They completed the visual acuity and Arden contrast sensitivity tests as performed in the previous experiment.

Exposure sessions

Two exposure sessions consisted of 5 minutes in the optokinetic drum rotating clockwise at 35 degrees per second (slightly greater than the 5 r.p.m. used in previous experiments). Subjects viewed the drum with their spectacles or contact lenses on for one session, followed by a 20 minute rest period, then viewed the same optokinetic stimulation without their spectacles or contact lenses. Six subjects commenced viewing with their vision corrected, and seven subjects commenced viewing with their vision uncorrected.

Subjects reported motion sickness scores each minute on the 7 point scale used previously and vection scores on the percentage scale as used in Experiments 4 and 5. During the exposure period, subjects were viewed on a video monitor to ensure that they had their eyes open and were looking straight ahead. Subjects did not complete motion sickness history questionnaires or post exposure symptom questionnaires. Symptoms were recorded during the five minute exposures merely to ensure that susceptible subjects did not reach excessive nausea or vomiting.

During exposures, eye movements were recorded using an IRIS (Skalar Medical Company) infra-red corneal reflection system, as described in Chapter 3. This allowed a resolution of 1 minute of visual angle of eye movement to be recorded, without the drift problems commonly associated with electro-oculography systems. The eye movements for each eye were recorded using an *HVLab* Data acquisition system at a sample rate of 300 samples per second, with a low pass filter cut off at 100Hz. Eye movements were calibrated for each eye separately before and after exposure 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 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* system at 300 samples per second.

The drum velocity was 35°/second, slightly higher than previous experiments where it was 30°/second. This higher speed was initially used in error for the first subject, in place of the 30°/second speed previously used, and then maintained for the remaining subjects.

Analysis

Eye movements

Only the data from the left eye were analysed for each subject because the infra-red sensor on the right eye had a tendency to move during the exposure. This was apparent by looking at the position of the sensors and confirmed by studying the calibration data before and after exposure. The left eye calibrations were consistent and were hence used for the analysis. Eye movements were analysed manually by inspection of the data files. A system was devised to ensure the values found were free from bias:

- Eye movement recordings were modified with reference to the calibration data corresponding to each file in order to make each file displayed as visual angle against time.

- The first 10 slow phase eye movements each minute, for each subject, were analysed.
- The slope of the slow phase was calculated by taking a point 0.02 seconds from the start and 0.02 seconds from the end of the slow phase, finding the difference in visual angle (in degrees).
- The difference in angle was divided by the time between the two points to give a slow phase eye velocity in degrees / second.
- The measurements were performed without any reference to individual visual acuity data for the subjects.

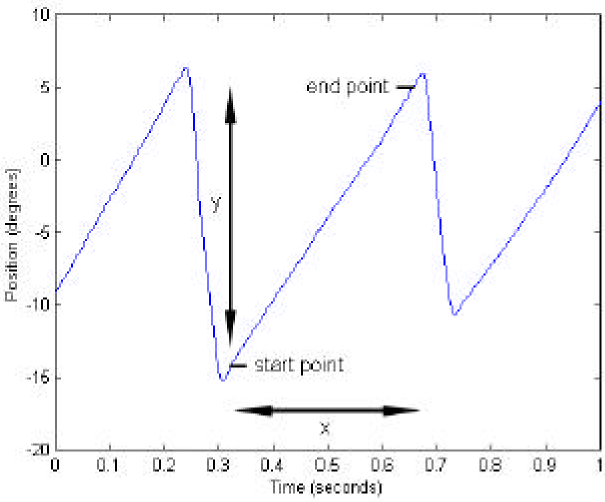

Figure 9.1. Calculation of slow phase velocity. Velocity = y divided by x. For illustration only – start and end points are not exact. Data shown is the first second for one subject.

Figure XX illustrates the process used to calculate the velocity of the slow phases. The first 10 slow phases of each minute were taken for a total of five minutes per subject giving a total of 50 measurements in each of the corrected and uncorrected conditions. A mean nystagmus frequency for each minute was also calculated by counting the number of slow phases which occurred in the first 10 seconds of each minute and dividing by 10 to calculate number of eye movements per second.

9.1.1 Statistics

Friedman tests were used to test whether there was any significant difference between the slow phase velocities recorded each minute, whether there was any significant difference between nystagmus frequencies recorded each minute and whether there was any significant difference between the subjective vection scores reported by subjects each minute.

An overall mean velocity was calculated for each subject from the 50 slow phase velocities found from the above procedure. The mean velocities for each subject for the two conditions were compared using the Wilcoxon matched-pairs signed ranks test. Nystagmus frequencies and motion sickness scores for the two conditions were also compared using the Wilcoxon matched-pairs signed ranks test.

Spearman's rank correlation test was used to study correlations between visual acuity, contrast sensitivity scores, mean nystagmus frequency and mean slow phase velocity.

9.2 Results

9.2.1 Motion sickness

There was no significant difference found in the accumulated illness ratings between conditions. This was not surprising given the very short exposure durations (Wilcoxon, $p>0.10$).

9.2.2 Eye movements

The mean slow phase velocity was 30.8°/second in the corrected vision condition and 29.26°/second in the uncorrected condition. The mean velocity of each subject (calculated from the 50 measurements of slow phase velocity per subject, in each of the conditions) was not significantly different between the uncorrected vision and the corrected vision condition (Wilcoxon, $p>0.10$). The frequency of nystagmus was not significantly different between the two conditions (Wilcoxon, $p>0.10$).

9.2.3 Friedman test

In order to test whether the slow phase velocities, nystagmus frequencies and subjective vection scores varied during the short exposure time, Friedman tests were performed. The results of the Friedman tests showed that there was no change in the slow phase velocity of nystagmus over the five minute period with correction (Friedman, $p>0.10$) or without correction (Friedman, $p>0.10$). There was no change in the frequency of nystagmus measured over the 5 minute period with correction (Friedman, $p>0.10$) or without correction (Friedman, $p>0.10$). There was a significant difference in the subjective vection scores recorded each minute with correction (Friedman, $p<0.000$) and without correction (Friedman, $p<0.000$). Study of the vection scores indicated that vection increased during the five minute exposure periods.

9.2.4 Spearman’s rank correlation test

Visual acuity, contrast sensitivity scores, the mean nystagmus frequency and the mean slow phase velocity were tested for significant correlations, using Spearman’s rank correlation.

9.2.4.1 Slow phase velocity - uncorrected vision condition

In the uncorrected vision condition, correlations were found between slow phase velocity and visual acuity measured at the near point (ρ=0.728, p<0.01), between slow phase velocity and contrast sensitivity at 1.25 cycles/° (ρ=-0.649, p<0.05) and between slow phase velocity and contrast sensitivity at 10 cycles/° (ρ=-0.554, p<0.05). There was a marginally significant correlation between slow phase velocity and contrast sensitivity at 2.5 cycles/° (ρ=-0.491, p=0.088). No significant correlations were found between slow phase velocity and visual acuity at the far point or between slow phase velocity and contrast sensitivity at 0.3,0.6,1.25 or 5 cycles/°. The correlations are shown in Table 9.1. A plot of slow phase velocity against visual acuity at the near point is shown in Figure 9.2 and a plot of slow phase velocity against contrast sensitivity at 1.25 cycles/° is shown in Figure 9.3.

Table 9.1. Correlations between slow phase velocity, visual acuity and contrast sensitivity (uncorrected vision).

Vision measurement, without correction	**Correlation with slow phase velocity**
Visual acuity at the near point	ρ=0.728 , *p*=0.005
Visual acuity at the far point	ρ=0.375 , *p*=0.206
Contrast sensitivity at 0.3 cycles/°	ρ=-0.088, *p*=0.775
Contrast sensitivity at 0.6 cycles/°	ρ=-0.455, *p*=0.118
Contrast sensitivity at 1.25 cycles/°	ρ=-0.649 , *p*=0.016
Contrast sensitivity at 2.5 cycles/°	ρ=-0.491 , *p*=0.088
Contrast sensitivity at 5.0 cycles/°	ρ=-0.397 , *p*=0.179
Contrast sensitivity at 10 cycles/°	ρ=-0.554 , *p*=0.050

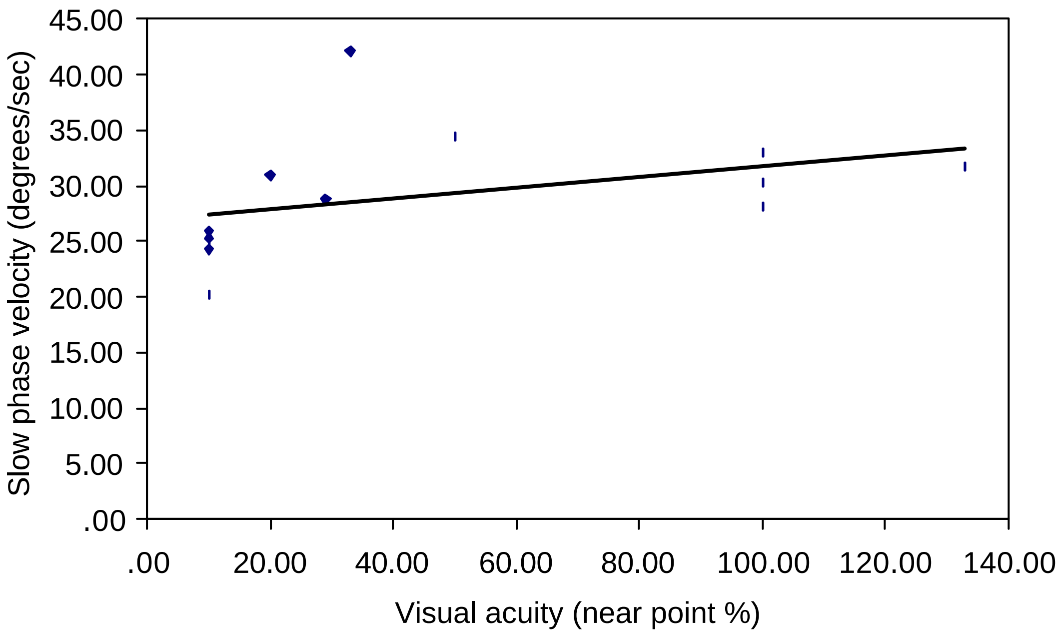

Figure 9.2. Variation of slow phase velocity for varying visual acuity, measured at the near point.

The significant correlation found between slow phase velocity and visual acuity at the near point was positive, indicating better visual acuity was associated with greater slow phase velocity. The correlations between slow phase velocity and contrast sensitivity scores were negative, also indicating that better contrast sensitivity (a lower score) was associated with a greater slow phase velocity.

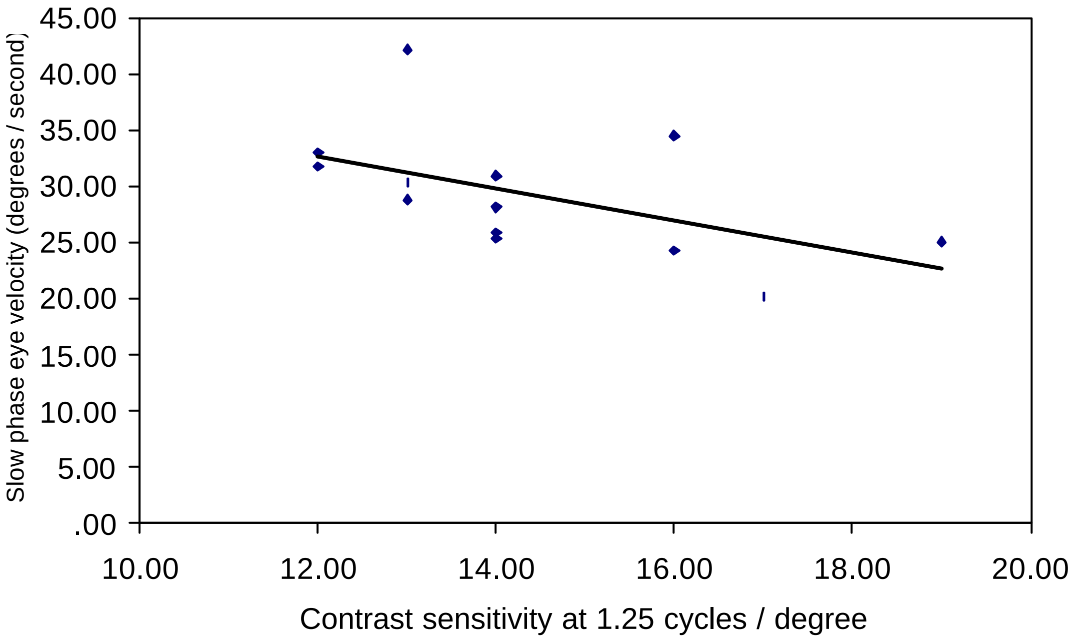

Figure 9.3. Variation of slow phase velocity with varying contrast sensitivity to 1.25 cycles per degree spatial frequency.

9.2.4.2 Slow phase velocity - corrected vision condition

In the corrected vision condition, no significant correlation was found between slow phase velocity and visual acuity at the near point (ρ=-0.231, p>0.10), nor between slow phase velocity and visual acuity at the far point (ρ=-0.231, p>0.10) (each subject had the same visual acuity at the near and at the far point, with correction, hence the correlations were the same). Significant correlations were found between slow phase velocity and contrast sensitivity at 0.3 cycles/degree (ρ=-0.609, p<0.05 – see Figure 9.4), between slow phase velocity and contrast sensitivity at 2.5 cycles/° (ρ=-0.598, p<0.05) and between slow phase velocity and contrast sensitivity at 5 cycles/° (ρ=-0.598, p<0.05 – see Figure 9.5). There was a marginally significant correlation between slow phase velocity and contrast sensitivity at 10 cycles/° (ρ=-0.549, p=0.052). No significant correlations were found between slow phase velocity and contrast sensitivity at 0.6 and 1.25 cycles/°. The correlations are shown in Table 9.2.

Table 9.2. Correlations between slow phase velocity visual acuity and contrast sensitivity scores (corrected vision condition).

Vision measurement, with correction	**Correlation with slow phase velocity**
Visual acuity at the near point	ρ=-0.231, p=0.447
Visual acuity at the far point	ρ=-0.231, p=0.447
Contrast sensitivity at 0.3 cycles/°	ρ=-0.609, p=0.027
Contrast sensitivity at 0.6 cycles/°	ρ=-0.469, p=0.106
Contrast sensitivity at 1.25 cycles/°	ρ=-0.527, p=0.064
Contrast sensitivity at 2.5 cycles/°	ρ=-0.575, p=0.040
Contrast sensitivity at 5.0 cycles/°	ρ=-0.598, p=0.031
Contrast sensitivity at 10 cycles/°	ρ=-0.549, p=0.052

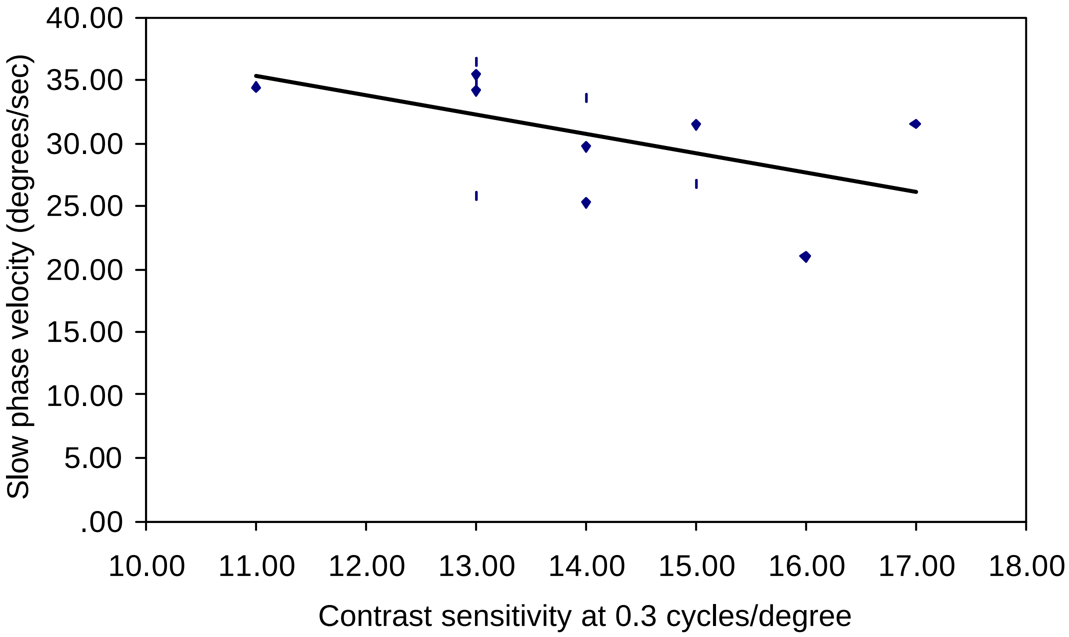

Figure 9.4. Variation of slow phase velocity with contrast sensitivity at 0.3 cycles/° in the corrected vision condition.

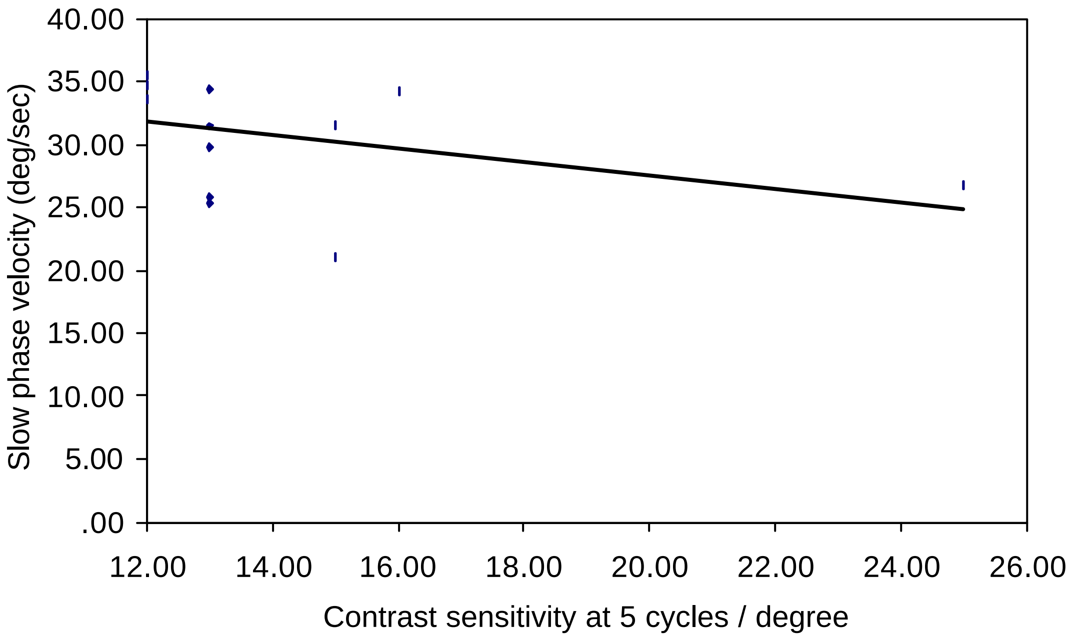

Figure 9.5. Variation of slow phase velocity with contrast sensitivity at 5 cycles/°, in the corrected vision condition.

9.2.4.3 Nystagmus frequency – uncorrected condition

In the uncorrected condition, there were no significant correlations between nystagmus frequency and visual acuity or contrast sensitivity scores. There was a marginally significant correlation between nystagmus frequency and visual acuity at the near point (ρ=0.512, p<0.10). There was no significant correlation found between nystagmus frequency and slow phase velocity (ρ=0.432, p>0.10) or between nystagmus and vection (ρ= -0.008, p>0.10). The correlations are shown in Table 9.3.

9.2.4.4 Nystagmus frequency – corrected vision condition

In the corrected vision condition, there were no significant correlations found between nystagmus frequency and visual acuity or contrast sensitivity scores. There was no significant correlation between nystagmus frequency and slow phase velocity, nor between nystagmus frequency and vection (ρ= 0.004, p>0.10). The correlations are shown in Table 9.4.

Table 9.3. Correlations between nystagmus frequency and vision measurements, without vision correction.

Variable (without correction)	Correlation with nystagmus frequency
Visual acuity at the near point	ρ=0.512, *p*=0.073
Visual acuity at the far point	ρ=0.132, *p*=0.667
Contrast sensitivity at 0.3 cycles/°	ρ=0.068, *p*=0.825
Contrast sensitivity at 0.6 cycles/°	ρ=-0.326, *p*=0.276
Contrast sensitivity at 1.25 cycles/°	ρ=-0.250, *p*=0.409
Contrast sensitivity at 2.5 cycles/°	ρ=-0.282, *p*=0.351
Contrast sensitivity at 5.0 cycles/°	ρ=-0.082, *p*=0.789
Contrast sensitivity at 10 cycles/°	ρ=-0.331, *p*=0.269
Slow phase velocity	ρ=-0.473, *p*=0.102
Vection	ρ=-0.004, *p*=0.979

Table 9.4. Correlations between nystagmus frequency and vision measurements, with vision correction.

Variable (with correction)	Correlation with nystagmus frequency
Visual acuity at the near point	ρ=-0.270, *p*=0.372
Visual acuity at the far point	ρ=-0.270, *p*=0.372
Contrast sensitivity at 0.3 cycles/°	ρ=0.097, *p*=0.753
Contrast sensitivity at 0.6 cycles/°	ρ=0.103, *p*=0.738
Contrast sensitivity at 1.25 cycles/°	ρ=-0.473, *p*=0.102
Contrast sensitivity at 2.5 cycles/°	ρ=-0.416, *p*=0.158
Contrast sensitivity at 5.0 cycles/°	ρ=-0.182, *p*=0.551
Contrast sensitivity at 10 cycles/°	ρ=-0.144, *p*=0.639
Slow phase velocity	ρ=-0.432, *p*=0.141
Vection	ρ= 0.004, *p*=0.989

9.3 Discussion

9.3.1 Slow phase velocity

The model predicted that slow phase eye velocity may be influenced by sensitivity to higher spatial frequencies and predicted that the velocity would be lower with lower sensitivity. The simple comparison of eye velocities recorded during the corrected and uncorrected conditions showed that the velocity of eye movements were slower in the uncorrected vision condition but the difference was not significant, as measured by the Wilcoxon test.

In the uncorrected vision condition there was a wide range of both visual acuity and contrast sensitivity at all of the spatial frequencies measured. The Spearman's rank correlation test showed that there was a correlation between visual acuity at the near point and slow phase velocity, of contrast sensitivity to the highest spatial frequency (10 cycles/°) and of contrast sensitivity to the 1.25 cycles/° spatial frequency. The correlations indicated that increased contrast sensitivity or increased visual acuity resulted in an increase in the slow phase velocity of the eyes in response to the optokinetic drum. The correlation between slow phase velocity and visual acuity was the most significant of the correlations measured, followed by contrast sensitivity at 1.25 cycles/° and then by contrast sensitivity at 10 cycles/°. The trend from these results is consistent with sensitivity to high spatial frequencies influencing the slow phase velocity of nystagmus. The correlation at 1.25 cycles/° shows that there may also be an influence of medium spatial frequencies on the slow phase velocity.

In the corrected vision condition, significant correlations with slow phase velocity were found at 0.3 cycles/°, 2.5 cycles/° and 5 cycles/°, with a marginally significant correlation found at 10 cycles/°. The variation in contrast sensitivity was less with vision correction, but there was still greater variation among the contrast sensitivity scores with vision correction than among the visual acuity scores (where all but one subject had greater than 20:20 vision). The correlations also showed that better contrast sensitivity (a lower score) was correlated with increased slow phase velocity. The correlations found with vision correction were unexpected. They occurred mainly at the higher spatial frequencies measured, with the exception of the 0.3 cycles/° frequency.

9.3.2 Nystagmus frequency

There was no significant difference between the frequency of nystagmus found with or without vision correction or any influence of visual acuity or contrast sensitivity on nystagmus frequency found. This may indicate that nystagmus frequency is determined mainly by the spatial frequency of the drum (i.e. the spacing between black and white stripes) rather than visual acuity or contrast sensitivity. Hu *et al.* (1997) found that varying the number of black and white stripes painted in an optokinetic drum could alter the average nystagmus frequency generated when subjects viewed the drum rotating at a constant velocity.

9.3.3 Effect of spectacle magnification on slow phase velocity

As mentioned in Section 8.5.4, there is a magnification or minification of the image viewed through spectacles. In the current experiment the main conclusions are drawn from the correlations between slow phase velocity and visual acuity and between slow phase velocity and contrast sensitivity scores, both found in the uncorrected vision condition. In the uncorrected vision condition there was no effect of magnification or minification because the subjects did not wear their spectacles or contact lenses in this condition. A difference in slow phase velocity would not be expected to occur due to the previous experience of the subjects, because head movements were restricted to prevent activation of the vestibulo-ocular reflex. The optokinetic drum activates the optokinetic and pursuit reflexes which are dependent on visual feedback, not past experience of magnification, in order to operate. It is concluded that the correlation between slow phase velocity and visual acuity is independent of the effect of magnification or minification of spectacles.

9.4 Conclusions

The reduction in velocity of the slow phase with decreased contrast sensitivity to higher spatial frequencies, means that subjects with poorer contrast sensitivity were less likely to make eye movements matching the speed of the stimulus which they were attempting to track, in this case the optokinetic drum. The model predicted two possible inputs to motion sickness: (i) via foveal image slip (ii) via eye movements directly, as hypothesised by Ebenholtz *et al.* (1994). This experiment confirmed that foveal image slip increased with reduced contrast sensitivity to high spatial frequencies, because of the inability of subjects with low contrast sensitivity to match the speed of the stimulus as effectively as those with high sensitivity to high spatial frequencies.

Since foveal slip velocity was correlated mainly with contrast sensitivity to high spatial frequencies, and motion sickness has been found to be influenced by visual acuity and contrast sensitivity, as discovered in the previous chapters, it is possible that a correlation would be found between motion sickness and foveal image slip velocity if the two were measured over a longer period than used in this experiment.

The hypothesis of Ebenholtz *et al.* (1994) that eye movements themselves are a cause of motion sickness, is less likely to be the route of the motion sickness effect. There were large differences between the motion sickness survival times of subjects with low and high acuity in previous experiments. However, the eye movements themselves were similar with and without vision correction. Variation in slow phase velocity of only a few degrees per second would result in a large increase in foveal image slip velocity, and perhaps a concomitant increase in motion sickness. Further discussion, and the final model, are presented in the next chapter.

The finding that contrast sensitivity was correlated with slow phase velocity in the corrected vision condition may indicate that the extra variation which occurred in the contrast sensitivity tests, compared with the visual acuity tests, could be used as a means of predicting the velocity of eye movements in response to a certain stimulus velocity , even when vision is corrected.

The slow phase velocity and nystagmus frequency did not change significantly during the five minute measurement periods in either the uncorrected or the corrected vision conditions. Vection did change during the same periods, in both conditions. This probably indicates that slow phase velocity, nystagmus frequency and vection are not related, as predicted from the initial model (Figure 2.22) and subsequent models. A final model is presented in the next chapter.