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The effect of binocular and monocular distractors on saccades in participants with normal binocular vision

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Abstract
We tested the effect of visual distractors presented monocularly and binocularly on saccade latency and accuracy to determine whether differences occur in saccadic planning with binocular or monocular visual input. For five participants with normal binocular single vision (BSV), saccade latency and accuracy were compared with distractors presented to the dominant eye, non-dominant eye or to both eyes. Eye movements of the dominant eye were recorded using a Skalar infra-red recorder. In the presence of normal BSV the effect of distractors is significantly larger for saccade latency and accuracy with binocular distractor presentation than for monocular presentations, with no difference between distrators presented to the dominant or non-dominant eye. The implications of these results are discussed with regard to saccade programming.
Keywords: Distractor; Binocular; Monocular; Saccade; Latency; Accuracy

Introduction
The latency and accuracy of target-elicited saccades can be altered by the presence of a peripheral distractor. Levy-Schoen (1969) was the first to show that saccadic latency was increased by up to 40ms when a distractor appeared simultaneously in a mirror symmetric position in the contralateral hemifield to the stimulus. However if the distractor appeared adjacent to the saccade stimulus, in the same hemifield, latency was unaffected but accuracy was compromised.

Walker et al., (1997) demonstrated that, for horizontal saccades, there was a reciprocal effect on saccade latency and accuracy depending on distractor location. Distractors presented within a window 20° around the horizontal target axis affected amplitude but did not influence latency. Distractors presented greater than 20° from the target axis increased latency but had no effect on amplitude. The latency increase reached a peak with distractors presented at the original fixation location. Other studies have also supported the finding of the remote distractor effect (Walker, et al., 2000; Adler et al., 2002).

The experimental test condition in previous distractor studies has been for the target and distractor to be presented to both eyes. The exception is the study by Walker, et al., (2000), which measured the distractor effect using monocular fixation and distractors presented monocularly in eight normal participants and six with hemianopia. However, comparison was not made to binocular distractor presentations for the same participants within the same experimental set-up. For many visual tasks binocular performance is superior to monocular performance, an effect referred to as binocular summation. As this superiority, of the two eyes over one, exceeds that predicted on the basis of statistical considerations alone (i.e. probability summation), binocular summation is thought to reflect neural interaction between the signals from the eyes (Blake & Fox, 1973). It is well established that binocular performance is greater for threshold tasks such as increment detection, form recognition, acuity and flicker fusion (Blake & Fox, 1973). Minucci and Connors (1964) reported differences in manual reaction time to stimuli presented binocularly, and stimuli presented monocularly in the dominant eye and non-dominant eye, over a range of light intensity levels. Overall reaction times to binocular stimuli were faster

than those to the dominant eye by 6% and faster than the non-dominant eye by 10%. Increased manual reaction times to visual stimuli in the presence of binocular distractors have also been found to be greater than the increase with monocular distractors (Justo et al., 2004).

However little attention has been given to the difference in response to distractors presented to the dominant or non-dominant eye with respect to programming and characteristics of eye movements. Moiseeva et al., (2000) evaluated differences in response to presentation of stimuli to the dominant and non-dominant eyes for latency of the peak of rapid pre-saccade potentials, using electroencephalograph (EEG) traces. They found an earlier appearance of EEG potentials in response to stimulation of the dominant eye and suggested that this might reflect greater rates of attention disengagement of fixation and faster sensory processing of the peripheral visual stimulus. Potentials immediately preceding the start of the saccades, which reflect the process of motor initiation, were increased during stimulation of the dominant eye suggesting a leading role for this eye in motor preparation in saccades.

As distractors hinder saccadic performance it is possible that the presence of distractors in both eyes would have a larger effect on saccade latency and accuracy than monocular presentation; this will be studied in this paper.

Ocular dominance, first described by Porta (1593), is where the input of one eye is favoured over the other. The dominant eye is thought to be more involved in visual direction and spatial localisation (Brod and Hamilton, 1971; Fowler and Stein, 1983) and it has been found to activate a larger area of the primary visual cortex than the non-dominant eye (Rombouts et al., 1996). The functional role of the dominant eye in vision and whether it truly is any indication of cerebral dominance is unclear (Mapp, et al., 2003).

Here we investigate the effects of distractor presentations to the dominant eye, nondominant eye and to both eyes, to determine whether the dominant eye has a greater input to saccade planning than the non-dominant eye, and whether differences to monocular and binocular distractor presentation exist. We also, as in Walker et al., (1997) explored the effect of different distractor locations, but in this paper we tested both monocular (dominant or non-dominant eye) and binocular distractor presentations. Note however that we report data only for the saccades of the dominant eye. A further motivation for the present study was to provide normal data that could be compared with the performance, in the same task, of strabismic participants with suppression of one eye (Griffiths et al, in preparation).

Methods

Participants

Five volunteers were recruited, with normal corrected visual acuity, bifoveal binocular single vision and stereoacuity of at least 60'' of arc using the TNO test. Their mean age was 20.6 years (range 19.0-21.8 years). Three participants were right eye dominant and two left eye dominant using the hole in the card test bi-manually (Walls, 1951). All were naive to the purpose of the study with no previous experience of eye movement studies. The study adhered to the Tenets of the Declaration of Helsinki.

Apparatus and stimuli

Eye movements were recorded using an IRIS 6500 infrared limbal tracker, (Skalar Medical, Delft, The Netherlands). The analogue output was filtered through a 100 Hz low-pass filter, digitised to 12-bit resolution and sampled at 5 ms intervals. Head movements were restricted by use of a chin and cheek rest. The eye movement recordings were stored on disk and analysed off-line. The laboratory set-up is shown schematically in Figure 1.

Figure 1 positioned here

A 1° cross target was presented by back projection in the centre of a translucent screen 114cm from the participant. A mirror galvanometer sited in front of the projector was used to reposition the target randomly at either 4° or 8° eccentricities along the horizontal axis. The target was always presented to both eyes.
A second projector with mirror galvanometer was used to back project a distractor onto the screen. The distractor consisted of an unfilled circle, diameter 1.5° which (when presented) appeared for 200ms simultaneously with the onset of the target. The target size, distractor size and distractor duration were selected following a pilot study run on two subjects. Those selected gave a distractor effect comparable with Walker et al., (1997). The targets were larger than Walker et al., (1997) but considered to be of an appropriate size to allow visibility by participants with mild to moderate amblyopia studied with the same task (Griffiths, 2003; Griffiths et al, in preparation). The 4° and 8° target amplitudes were selected to be comparable to the experiments of Walker et al., (1997).

In the experiment three distractor conditions were used; distractor to both eyes simultaneously, to the dominant eye only, to the non-dominant eye only. As shown in Figure 1, distractor presentation to one or both eyes was controlled by 4 liquid crystal polymer (LCP) shutters (Phillips Components), one positioned between the lens and the mirror galvanometer of each projector and one positioned in front of each of the participant's eyes. The LCP shutters were normally highly transparent. Application of an electrical field caused the LCP to turn instantly turbid, scattering light. All 4 shutters were run at a frequency of 80Hz. Alteration of the relative timings of the shutters allowed presentation of the distractor to one eye or both eyes. A series of experiments confirmed that the shutters did not allow any crosstalk between the eyes (Griffiths, 2003). A stationary background comprised of fine random dots of luminance 2cd/m_2 was back projected by a third slide projector, Figure 1, and was visible to both eyes at all times. Room illumination was kept constant throughout the experiment at 1cd/m_2.

Procedure

A clinical examination was initially performed to determine presence of normal binocular single vision, level of visual acuity and eye dominance (for details see participants section).
The participant was seated with the Skalar infrared eye movement recorder and LCP shutters in place. Before each block of 20 trials the participant was informed/reminded that all targets would initially appear in the centre of the screen and always move to the right and then back to the centre. This direction was maintained for all subsequent trials to avoid any increase in latency on distractor trials caused by the additional discrimination process required to select the correct target direction. Participants were instructed to look directly at the centre of the small cross positioned in the middle of the screen and when it jumped to the right, to move

their eyes as quickly and accurately as possible to look at the centre of the cross. They were told not to anticipate the target movement and that they should only move their eyes when they saw it appear. They were told that occasionally a circle (i.e. the distractor) could appear anywhere on the screen, but this should be ignored at all times.
Eye movements generated using a sinusoidal target motion of 0.32Hz, ±12°, were used to calibrate the eye movement recorder before each block of 20 trials. Participants were asked to follow the centre of the target as accurately and smoothly as possible.

Figure 2 shows schematically the target and distractor positions. The target was initially presented centrally. To avoid anticipation there was a random period (500 to 1200ms) before the target disappeared and immediately reappeared at either 4° or 8° on the horizontal axis for 500ms (0 gap). The target then returned to the centre point before the next presentation. In most trials a distractor appeared simultaneously with the onset of the 4 or 8° target for 200ms. The eccentricity of the distractor varied randomly between ±10° at 2° intervals along the horizontal axis, where positive values represent distractors ipsilateral to the target and negative values represent distractors on the contralateral side to the target. Zero indicates distractors presented at the original fixation point. In 60 out of 720 trials, one per block, no distractor was presented. The mean data from this condition provided baseline measures. A total of 12 blocks of trials, each consisting of 20 saccades, was run for each distractor condition (distractor to both eyes, dominant eye and non-dominant eye) in a random order, giving 20 saccades at each distractor eccentricity, 240 saccades for each distractor condition and a total of 720 saccades. The experiment was carried out over three testing sessions each of 45 minutes completed within a ten-day period.

Figure 2 positioned here

Results

Saccades were detected using an acceleration criterion, which defined the start of a saccade as occurring when eye acceleration exceeded twice the noise level. Each saccade was then checked visually to confirm correct detection of the primary saccade.
Mean saccade latency and gain for each participant was calculated for each distractor eccentricity and for each of the three types of distractor. Saccades with latency <80ms were excluded as they were considered to be anticipatory (Fischer & Weber, 1993) and saccades with latency >450ms were excluded as they were not considered to be visually triggered (Walker et al., 1997). Also in all participants a small number of saccades could not be analysed due to blinks or incorrect fixation. A total of 14% of saccades was therefore excluded from the analysis.

Saccade Latency

Data was similar across participants and was therefore pooled for the graphs. The mean latencies obtained for single targets (no distractor) at 4° and 8° were 150ms (SD =11.9) and 150ms (SD=15.8) respectively, are shown as the horizontal lines in Figures 3a and 3b, respectively. Figure 3 also shows the mean saccade latency pooled for the group plotted as a function of distractor eccentricity with distractors presented to both eyes, the dominant eye and the non-dominant eye.

Figure 3 positioned here

When comparing the three types of distractor presentation, a slightly greater effect was demonstrated with the distractor at the original fixation point to both eyes compared to monocular presentation (either dominant or non-dominant eye) in all participants. For 4° targets latency increased with the distractor at fixation by 66ms when presented to both eyes simultaneously; 53ms when presented to the dominant eye; 42ms when presented to the non-dominant eye. For 8° target eccentricity with the distractor at fixation saccade latency increased by 59ms when the distractor was presented to both eyes simultaneously, 48ms when presented to the dominant eye and 44ms when presented to the non-dominant eye.

To establish whether at the fixation point this difference between distractors to the dominant, non-dominant or both eyes was significant a 3 Factor Repeated Measures analysis of variance (ANOVA) compared saccade latency obtained with distractors at fixation and without distractors. The three factors were: Eye viewing the distractor (dominant, non-dominant or both eyes), Target amplitude (4° and 8°) and Distractor (no distractor or distractor at fixation). This revealed no significant difference between the two target amplitudes, $F_{1,4} <1$, not significant (n.s.), or eye viewing distractor, $F_{2,8} = 2.53$, n.s.. The largest effect was for presence of a distractor at fixation or absence of distractor, $F_{1,4} = 65.0$, $p<0.01$. No significant interactions were found between any of the factors.

It can be seen that for both 4° (Figure 3a) and 8° target amplitudes (Figure 3b) saccade latency increased when distractors appeared in the contralateral non-target hemifield with maximum increase with distractors at fixation. There was also a small increase in latency with distractors on the ipsilateral side to the target at +2°. Latency was unaffected by distractors presented between 4° and 10° along the ipsilateral target axis.

The main purpose of our study was to test for differences in the remote distractor effect when the distractor is presented to both eyes together or the dominant or the non-dominant eye. In order to test for this and other effects a 3 Factor Repeated Measures ANOVA was conducted on the latency data. The 3 factors were Target amplitude (4_o or 8_o), Eye viewing the distactor (both, dominant or non-dominant) and Distractor position (-10, -8, -6, -4, -2, +2, +4, +8 and $+10_o$ note that the 0_o distractor position was not included in this analysis as it is not a remote distractor, see analysis above).

There was no overall significant difference between the latencies of the 4_o and 8_o targets $F_{1,4} <1$, n.s., or any significant interactions with this factor and any others (highest $F_{1,4} = 1.06$, n.s.) clearly therefore target amplitude had no significant effect on latencies in any of the conditions (this is true of all the latency analyses described below). There was no overall significant difference between the eye in which the distractor appeared, $F_{2,8} <1$, n.s. but there was a significant effect of distractor position, $F_{9,36} = 15.1$, $p <0.0001$. Also the effect of distractor position depended on the eye to which the distractor was presented with the Eye x Position interaction being significant $F_{18,72} = 3.59$, $p <0.0001$. These effects can be seen in Figure 3. The significant interaction appears to be caused by the difference between the both eyes condition and the other two conditions. This was supported by the result of a further 3 Factor ANOVA conducted as above but with the both eye data removed[1]. The Eye x Position interaction was now not significant, $F_{9,36} = 1.13$, n.s, but with the Distractor position effect still significant, $F_{9,36} = 7.63$, $p <0.0001$. [2]

As described earlier, from Figure 3 it appears that the remote distractor effect is greater when the distractor is presented on the contralateral than the ipsilateral side. This was explored in 2 separate 3 Factor ANOVAs, both with factors: Target amplitude (4_o or 8_o) and Eye viewing the distactor (both, dominant or non-dominant). The contralateral analysis had a Distractor position factor with levels (-10, -8, -6, -4

and -2) and the ipsilateral analysis had levels (+2, +4, +8 and +10o). Both analyses showed a significant Distractor position effect, for the contralateral $F_{4,16} = 23.5$, $p < 0.0001$ and for the ipsilateral $F_{4,16} = 7.47$, $p < 0.01$. However, the Distractor position effect for the ipsilateral analysis, and see Figure 3, seems to be caused by the +2o distractor position data, and when this data is removed in a further 3 factor ANOVA
The data could have been explored further with a set of post-hoc tests. However, we decided against this as there were too many means to be compared for most tests other than a large set of t-tests and with our study having N=5 such tests seemed excessive. The analysis described seemed to provide what we required with the pattern of findings in a series of ANOVAs changing as data was removed.
Note that two separate ANOVAs done with either the Dominant eye and Both eye data or the Non-Dominant eye and the Both eye data both showed the same pattern of results as the complete analysis with all 3 eye conditions. This again indicates that the remote distractor effect on latencies is no different for the dominant and non-dominant eye.the effect becomes non-significant $F_{3,12} = 2.56$, n.s. We shall discuss later what may be causing this position effect at +2o on the ipsilateral side. Note that when, for the contralateral Analysis, the -2o Distractor position data is removed the Distractor position effect is still present, $F_{3,12} = 6.84$, $p < 0.01$, again indicating that the remote distractor effect is stronger, and present at more distractor positions on the contralateral side.

The latency data were further examined. The mean latency in the no distractor condition was calculated for each participant. For each distractor position the percentage of saccades with latencies >2 standard errors from their no distractor mean was then calculated for each participant. The pooled data for the 5 participants is shown in Figure 4.

Figure 4 positioned here

This representation of the data shows more clearly than in Figure 3 the difference between distractors presented on the contralateral and ipsilateral side. For the contralateral distractor positions on average always 40% or more of the saccadic latencies were increased by a value outside at least 2 standards errors of the data from the matching no distractor conditions. In contrast for the ipsilateral distractor positions on average all (except for the +2o conditions) had 30% or less of the saccadic latencies similarly increased.
A 3 Factor Repeated Measures ANOVA was conducted on the data of Figure 4, the factors were Target amplitude (4o or 8o), Eye viewing the distactor (both, dominant or non-dominant) and Distractor position (-10, -8, -6, -4, -2, +2, +4, +8 and +10o). The findings were the same as the ANOVA performed on the data of Figure 3: The effect of Distractor Position was significant, $F_{9,36} = 99.2$, $p < 0.0001$ and the effect of distractor position depended on the eye to which the distractor was presented with Eye x Position interaction being significant, $F_{18,72} = 2.04$, $p < 0.05$. All other factors and interactions were not significant (highest $F_{18,72} = 1.25$, n.s.).
Rather than test the data in Figure 4 with a series of ANOVAs the finding can perhaps be better summarized with the results of a few t-tests. For the 4 degrees amplitude stimuli, Figure 4a, the lowest value from contralateral distractors (45.6%) is for when the distractor is presented to both eyes at the –10o position. These data were compared in 15 separate repeated measures t-tests with all the data from the ipsilateral distractors, in Figure 4a, and 9 were significant at least at $p < 0.05$ (smallest significant t=2.92, d.f. = 4), and with 3 of the non-significant t-tests arising from the +2o condition (see later discussion). Similarly, for the 8-degree amplitude

stimuli, Figure 4b, the lowest value on the contralateral side (44.2%) was for the condition where the distractor was presented to the non-dominant eye in the –10° position. These data were then compared in a series of paired scores t-tests, as above, with the ipsilateral data, Figure 4b. Here 11 of the 15 t-tests were significant at least at $p < 0.05$ (smallest t=2.88, d.f.=4) with 3 of the 4 non-significant comparisons again arising from the +2° condition (see later discussion).

Saccade accuracy

Saccade gain was taken to represent a measure of saccade accuracy, calculated by dividing the change in eye position by the change in target position, hence a gain of

1 equals a saccade precisely reaching the target, >1 equals a hypermetric saccade and <1 equals a hypometric saccade.

Data were similar across participants and were therefore pooled for the graphs. From pooled data the mean gain obtained for single targets (no distractor) at 4° and 8° was 1.001 (SD=0.045) and 0.971 (SD=0.072) respectively and is shown as the horizontal line in Figures 5a and 5b. Figure 5 shows the mean saccade gain pooled for the group plotted as a function of distractor eccentricity with distractors presented in both eyes, dominant eye and non-dominant eye.

Figure 5 positioned here

Accuracy appears unaffected by contralateral distractors to target location but was affected by ipsilateral distractors. With the distractor between fixation and the target, the saccade undershoots the target (hypometric), whereas with the distractor at greater amplitudes to the target the saccade overshoots the target (hypermetric). From the pooled data for 4° and 8° target presentation, gain was lowest when the distractor was at 2°, i.e. distractor between fixation and the target. Saccade gain was highest when the distractor was at 10°, i.e. with the distractor at greater amplitudes than the target.

When comparing monocular and binocular distractor conditions, a greater effect (lower accuracy) was demonstrated when the distractor was presented to both eyes in all participants, this is shown in Figure 5. For 4° targets gain decreased with the distractor at 2° compared with the no distractor condition, by 0.220 when the distractor was presented to both eyes simultaneously; 0.128 when presented to the dominant eye; 0.049 when presented to the non-dominant eye. Saccade gain increased with the distractor at 10° by 0.824 when the distractor was presented to both eyes simultaneously; 0.240 when presented to the dominant eye; 0.352 when presented to the non-dominant eye. For 8° target presentation gain decreased maximally with distractor at 2° by 0.382 when the distractor was presented to both eyes simultaneously; 0.232 when presented to the dominant eye; 0.135 when presented to the non-dominant eye.

In order to test for the effect of distractors on saccadic gain seen in Figure 5 a 3 Factor Repeated Measures ANOVA was conducted. The 3 factors were Target amplitude (4° or 8°), Eye in which distractor appeared (both, dominant or nondominant) and Distractor position (-10, -8, -6, -4, -2, +2, +4, +8 and +10° note again that the 0° distractor position was not included in this analysis). All factors and interactions were significant, smallest $F_{18,72} = 7.03$, $p < 0.0001$, reflecting the more complex pattern of results apparent for gain, Figure 5, than for latency, Figure 3. Importantly for the gain data there was an overall significant effect of Eye viewing the distactor, $F_{1,4} = 7.69$, $p < 0.05$, and the amplitude of the target had different significant effects on the gain, $F_{1,4} = 44.979$, $p < 0.01$, as can be seen in Figure 5.

The distractor position had a significant effect on gain, $F_{9,36} = 35.2$, $p < 0.000$, but this depended on the eye viewing the distractor, $F_{18,72} = 11.4$, $p < 0.0001$, for the Eye x Position interaction.
From Figure 5 it appears that the significant interactions associated with the eye viewing the distractor reflect a larger effect for the both eyes conditions compared with dominant or non-dominant eye conditions. This was confirmed in a 3 Factor Repeated Measures ANOVA with the both eye condition data removed. Here both the Eye factor and all interactions with this factor now became non-significant, highest $F_{1,4} = 4.76$, n.s. for a factor and $F_{9,36} = 1.31$, n.s. for an interaction.[3]
Inspection of Figure 5 shows a marked difference in the effect of distractors presented to the Contralateral or Ipsilateral side. This was explored in two separate 3 factor ANOVAs, with the same factors and levels as the ANOVA conducted on all the data. The Contralateral data analysis found no significant effects, highest $F_{1,4} = 5.93$, n.s., and with all interactions being non-significant, highest $F_{8,32} = 1.12$, n.s.. This contrasts markedly with the Ipsilateral data analysis where all factors and interactions were significant, smallest $F_{4,16} = 3.96$, $p < 0.05$. The pattern of results for the Ipsilateral data was the same as for the complete analysis, showing that those mainly arose from the Ipsilateral data.

Discussion

The remote distractor effect for binocularly presented distractors as previously described by Walker et al., (1997) was closely replicated in our laboratory set-up using a 1.5° distractor presented for 200ms simultaneously with the onset of the target. A difference between the studies is evident however for ipsilateral distractors at +2°. Walker et al., (1997) reported no increase in latency in this position whilst the current study showed an increase in the region of 18ms. This may have been due to the larger distractor diameter used in the present study. Neurons within the rostral pole of the superior colliculus, which respond during active fixation, represent a central 2° area of the visual field (Munoz and Wurtz, 1992, 1993a, b). These cells were more likely to be stimulated with the 1.5º distractor used in the present study as the outer edge of the distractor was 1.25° from the original fixation point, approaching the 2° central area. This may have made release of fixation more difficult, therefore increasing the saccade latency.
Figures 3, 4 and 5 demonstrate that the effect of distractors is similar for dominant and non-dominant eye presentations hence the dominant eye appears not to have a greater control over saccadic planning. Although a small difference was found, with distractors to the dominant eye apparently having a slightly greater effect on latency and accuracy, this difference was small and not found to be significant in any statistical analyses.
The results show significant differences in monocular and binocular distractor presentations for latency and accuracy (Figure 5). A greater difference in saccade latency occurred with binocular distractors compared with monocular distractors (Figure 3) and this difference was significant for both target amplitudes. Distractors appearing simultaneously to both eyes gave rise to a significantly increased effect on saccade accuracy compared with monocular presentations for both 4° and 8° targets (Figure 5).
Walker et al., (2000) measured the distractor effect using monocular fixation and distractors presented monocularly in 6 normal participants. They found a small difference in the saccade latency increase for temporal field distractors (15ms) compared to nasal field distractors (7ms) however this was not statistically significant. Rafal et al (1991) reported that crossed pathways show dominance in saccade elicitation, although this is not well supported (Walker et al, 2000). As only

one target direction was used in the current study, eye dominance is confounded with nasal/ temporal visual field. The data was therefore re-analysed comparing distractor presentations to the right eye and left eye (irrespective of eye dominance). This did not reveal any differences in the reported results.

In summary, the findings of this current study are that distractors presented to the dominant eye or non-dominant eye had equal effect on both saccade latency and accuracy of the dominant eye. It was concluded therefore that each eye has equal input into saccade generation. Binocular distractors were found to cause a greater difference in latency, for contralateral distractors compared to ipsilateral distractors, than monocular distractor presentations. The effect of binocular distractors on saccade gain was significantly larger than monocular distractor presentations. Therefore in BSV the summated sensory signal has a greater effect on the motor response.

The effects of distractors at fixation on saccade latency have been attributed to an increase in activation of the fixation region of the superior colliculus (SC), which is thought to inhibit triggering a saccade (Dorris and Munoz, 1995; Munoz and Wurtz, 1993a & b, 1995a & b). Walker et al., (1997) concluded that these inhibitory effects operate over a wider visual field as they found that distractors at any location in the visual field, except a narrow sector around the target axis, affected saccade latency. Modification of this theory has been suggested (Olivier et al., 1999), due to findings reported by Krauzlis et al., (1997), that the visual receptive fields of collicular fixation neurons are small and encompass only foveal and parafoveal regions of the contralateral visual field. Olivier et al., (1999) proposed that the effect seen on latency may be due to a lateral inhibitory network within the intermediate layers of the SC. Presentation of a remote distractor would activate a second population of saccade-related neurons and lateral inhibitory interactions would therefore delay the motor command to initiate a saccade.

In the present study as shown in Figure 3, the increased saccade latency for binocular distractor presentations at fixation, compared to monocular presentations at fixation and the larger contralateral to ipsilateral difference with binocular distractors may represent a larger inhibitory effect in the intermediate layers of the SC in binocular distractor presentations. Recordings of collicular activity in the monkey during binocular and monocular distractor presentations or EEG studies in humans could investigate this suggestion.

The effect of distractors presented in the ipsilateral hemifield on saccade accuracy, where, as shown in Figure 5, the saccade is directed to an intermediate position between the target and distractor (the global effect) has been attributed to the activity of collicular burst cells. From recordings of the superior colliculus of the monkey it has been found that two stimuli, if closely located, produce a single intermediate peak of activity (Glimcher & Sparks, 1993). Olivier et al., (1999) suggested that lateral interaction within the intermediate layers of the SC may also explain this response. They proposed that presentation of a distractor in close proximity to the target would activate a second population of saccade-related neurons in overlapping receptive fields. Lateral excitatory interactions would therefore modify the motor command affecting the spatial saccade parameters.

This present study demonstrated a larger distractor effect on saccade gain for binocular compared to monocular distractor presentations, seen in Figure 5. We speculate that distractor stimulation in both eyes activates a wider population of saccade-related neurons in overlapping receptive fields, than monocular distractor presentation, leading to greater modification of the motor command. Studies of activity in the intermediate layers of the monkey SC with monocular and binocular distractors would confirm this or EEG or *f* MRI studies in humans.

Conclusion
A strong effect of distractors on saccade latency and accuracy of the dominant eye has been shown in participants with normal binocular single vision. The effect is not notably different with distractors presented to either the dominant or non-dominant eye. A clear enhanced binocular response has been demonstrated in the remote distractor effect, such that distractors presented to both eyes have a greater effect on saccade latency and gain than monocular presentations in the presence of normal bifoveal BSV.

The finding of an increased binocular distractor effect has been compared by the authors in further studies of participants with constant strabismus and suppression and no clinically demonstrable binocular interactions. Responses to distractors presented only to the suppressed eye has also been explored, (Griffiths, 2003; Griffiths et al., in preparation)

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Figure 1: Schematic of the laboratory set-up. Projector 1 displayed the target visible

to both eyes at all times, projector 2 presented the distractor as required, projector 3 was used to present a stationary background and was positioned centrally, shown here positioned obliquely for clarity. The LCP shutters were used to present the distractor appropriately to either the dominant eye, non-dominant eye or both eyes.

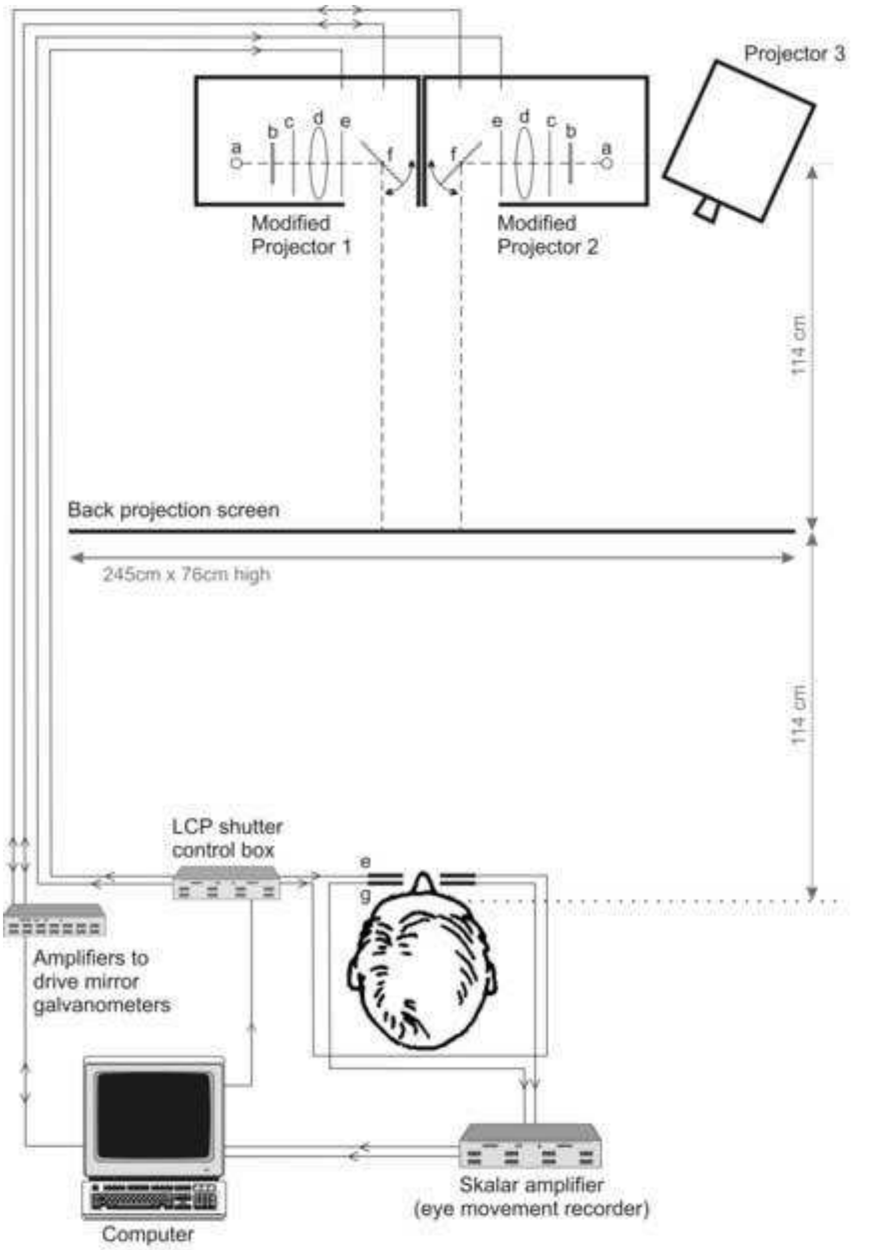
Figure 2: Schematic diagram of target and distractor positions. Positive values represent positions to the right of the participant's central fixation point and negative values to the left.

Figure 3: Effect of distractors on saccade latency. Saccade latency in milliseconds (ms) plotted as a function of distractor position; a) target presented at +4° (to the right), b) target presented at +8° (to the right). Pooled data for five participants, error bars represent ±1 standard error of the mean. Distractor position zero indicates distractor presented at the original fixation point, positive values distractor positions are rightward and ipsilateral to the target, negative values distractor positions are leftward and contralateral to the target.

Figure 4: Percentage of saccade latencies > 2 standard errors from the mean of the no distractor condition. Pooled data for five participants, error bars represent ±1 standard error of the mean.

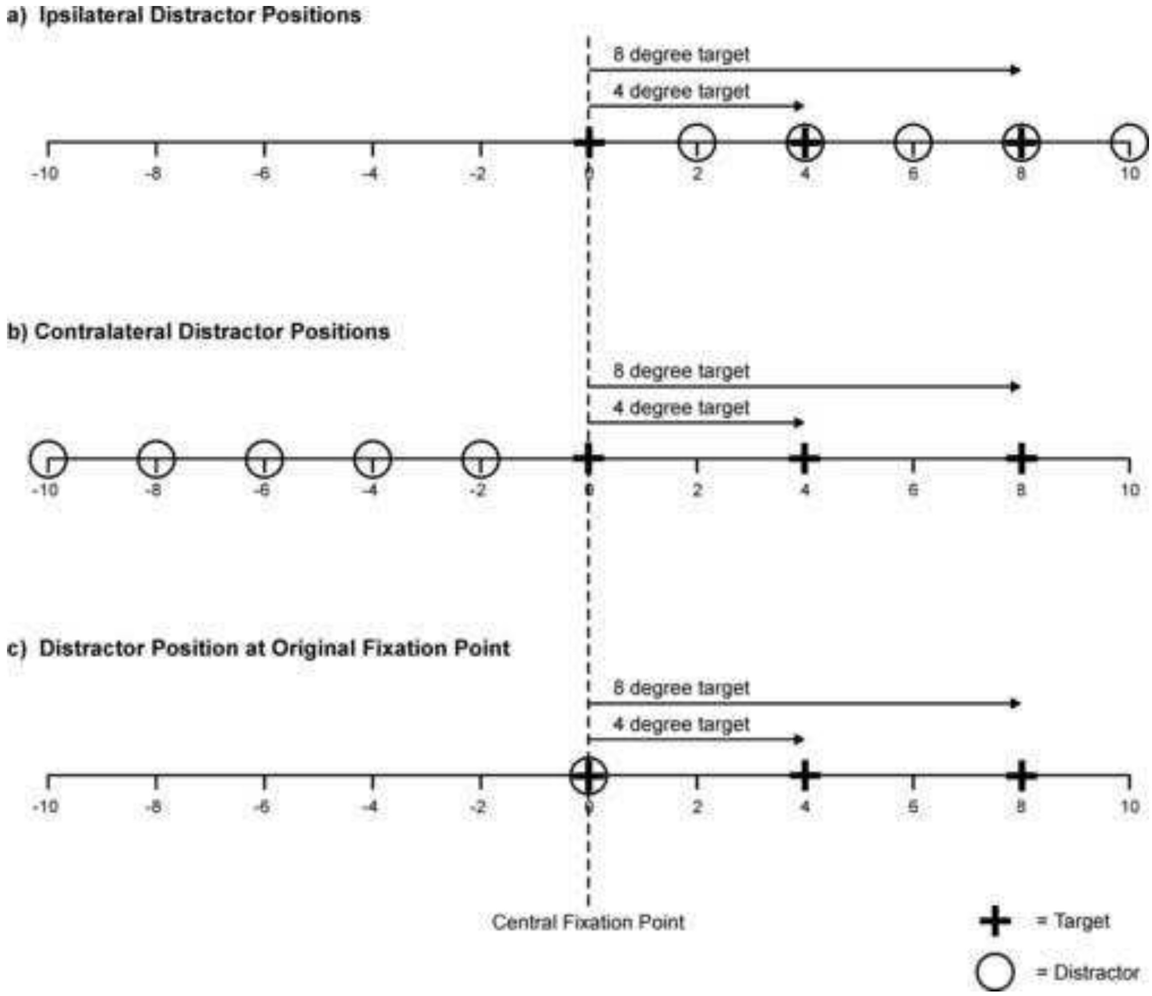
Figure 5: Effect of distractors on saccade accuracy. Saccade gain (saccade amplitude/ target amplitude) plotted as a function of distractor position; a) target presented at +4°, b) target presented at +8°. Pooled data for five participants, error bars represent ±1 standard error from the mean. Distractor position zero indicates distractor presented at the original fixation point, positive values distractor positions are rightward and ipsilateral to the target, negative values distractor positions are leftward and contralateral to the target.

Figure 1



a = Lamp
b = Target Slide
c = Metal Shutter
d = Projector Lens
e = Liquid Crystal Polymer Shutter
f = Mirror Galvanometer
g = Skalar Infra-red eye tracker

Figure 2



a) Ipsilateral Distractor Positions
8 degree target
4 degree target
-10
-8
-6
-4
-2
0
2
4
6
8
10
b) Contralateral Distractor Positions
8 degree target
4 degree target
-10
-8
-6
-4
-2
0
2
4
6
8
10
c) Distractor Position at Original Fixation Point
8 degree target
4 degree target
-10
-8
-6
-4
-2
0
2
4
6
8
10
Central Fixation Point
= Target
= Distractor

Figure 3

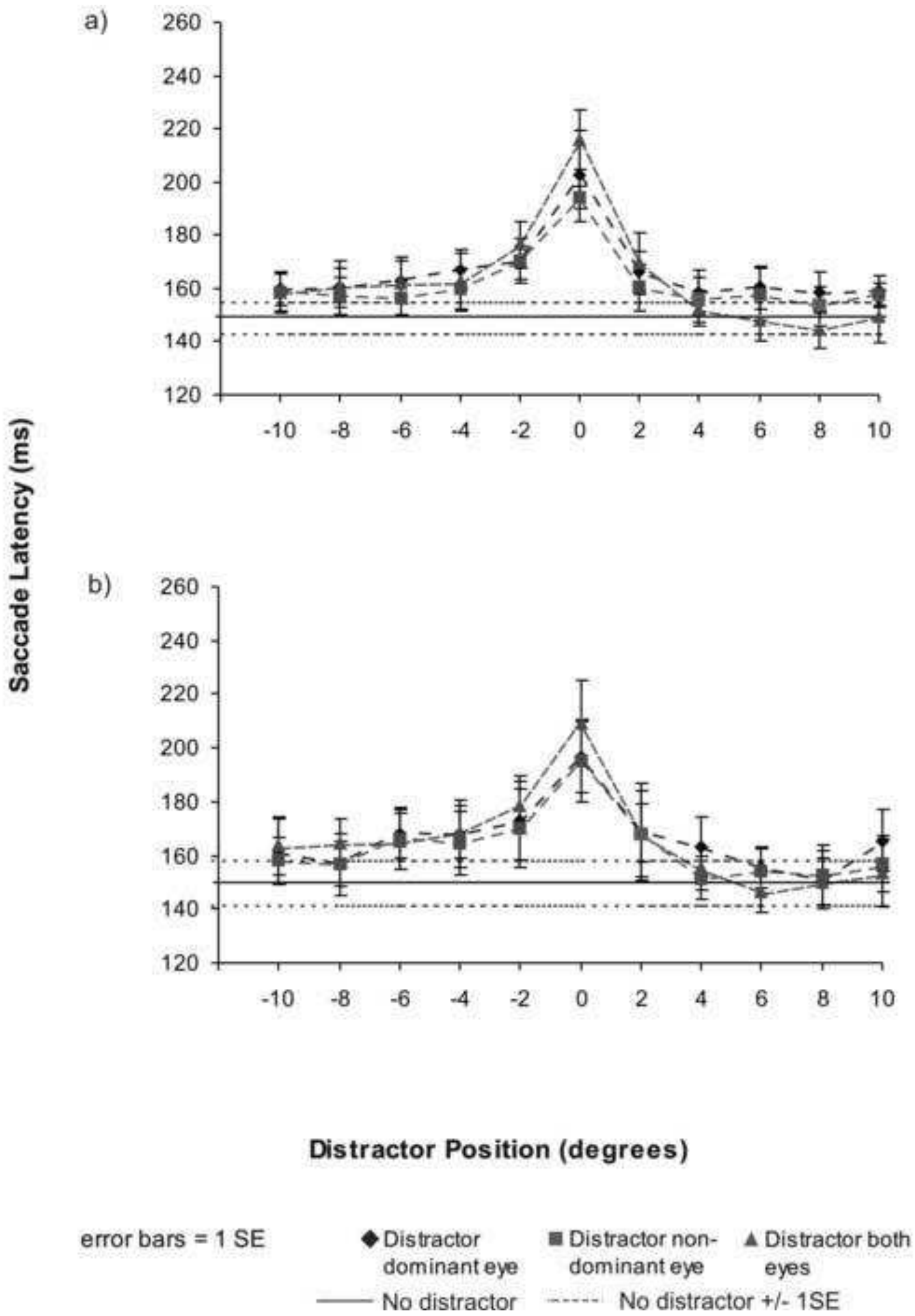

a)
b)
260
240
220
200
180
160
140
120
-10
-8
-6
-4
-2
0
2
4
6
8
10
Saccade Latency (ms)
Distractor Position (degrees)
error bars = 1 SE
Distractor dominant eye
Distractor non-dominant eye
Distractor both eyes
No distractor
No distractor +/- 1SE

Figure 4

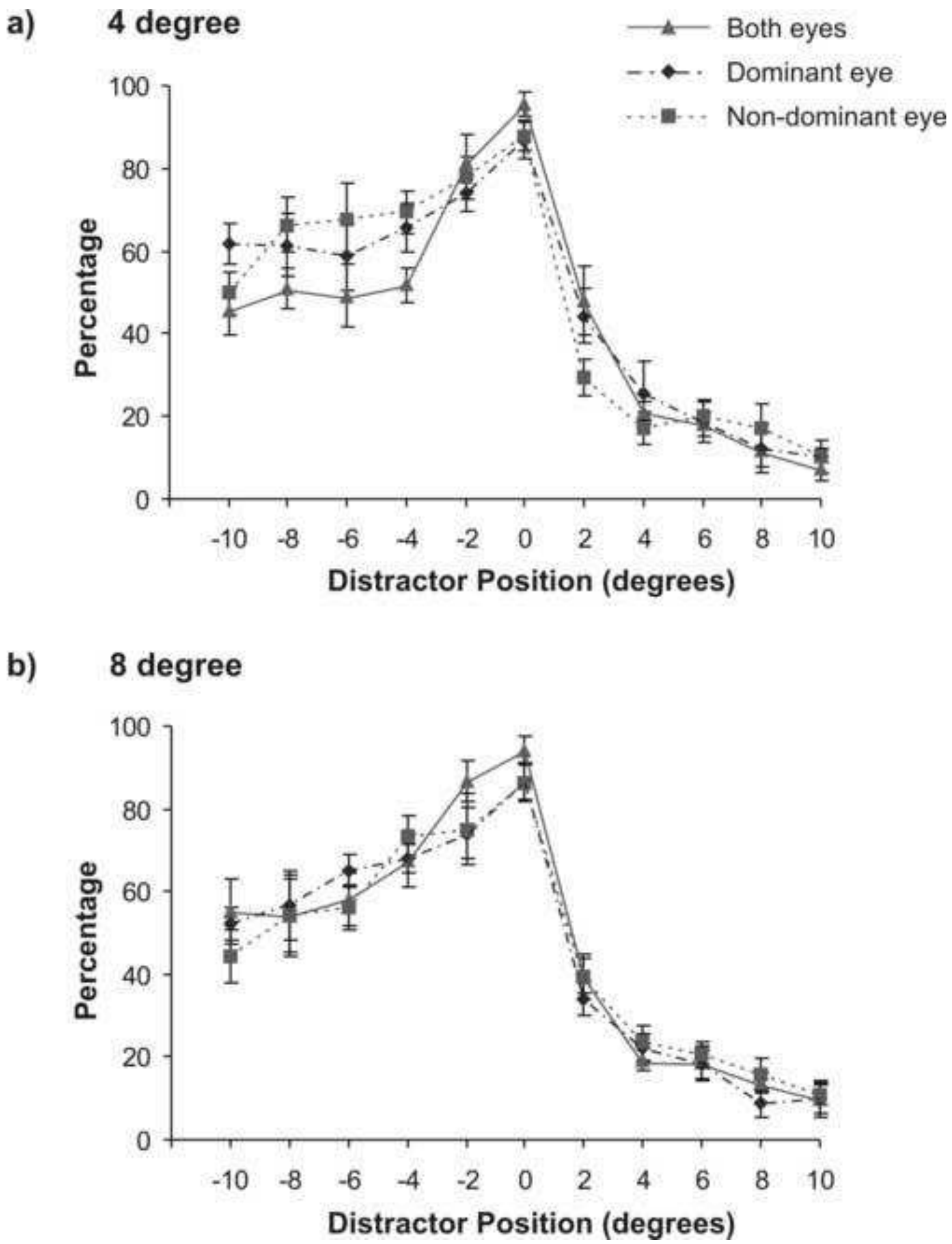
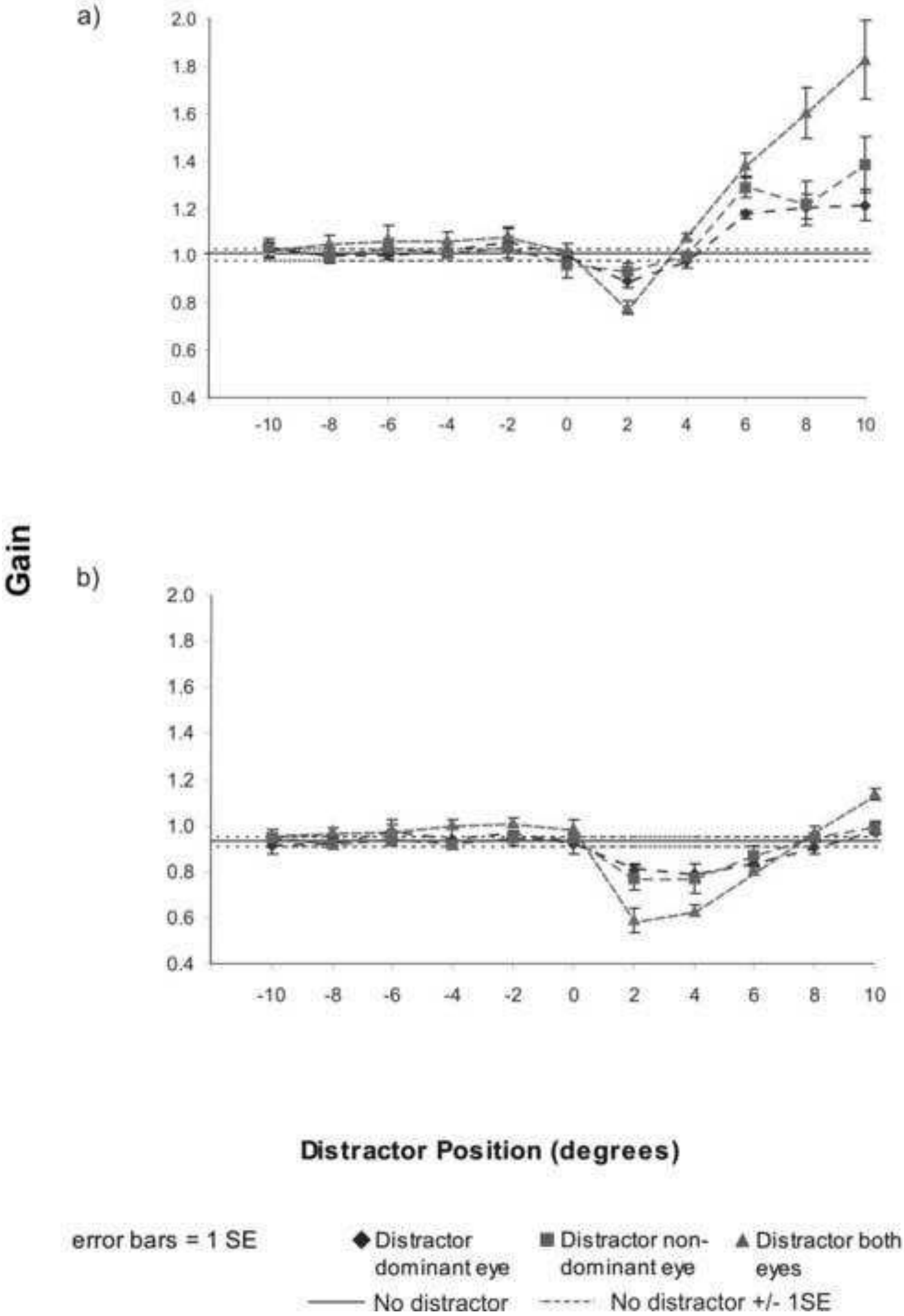

a)
4 degree
Both eyes
Dominant eye
Non-dominant eye
Percentage
100
80
60
40
20
0
-10
-8
-6
-4
-2
0
2
4
6
8
10
Distractor Position (degrees)
b)
8 degree
Percentage
100
80
60
40
20
0
-10
-8
-6
-4
-2
0
2
4
6
8
10
Distractor Position (degrees)

Figure 5


a)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
-10 -8 -6 -4 -2 0 2 4 6 8 10
Gain
b)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
-10 -8 -6 -4 -2 0 2 4 6 8 10
Distractor Position (degrees)
error bars = 1 SE
Distractor dominant eye
Distractor non-dominant eye
Distractor both eyes
No distractor
No distractor +/- 1SE