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Effect of induced changes in oculomotor posture on spatial judgment

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Abstract
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Effect of Induced Changes in Oculomotor Posture on Spatial Judgment

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ABSTRACT

This investigative study was designed to determine whether or not changes in oculomotor posture (fixation disparity and/or heterophoria) induced by prism wear have a consistent effect on spatial errors in a visually guided motor task. Previous studies have demonstrated that inducing changes in heterophoria causes errors in distance judgments, but little research has addressed the effect of fixation disparity on spatial judgments. Theoretically, fixation disparity misalignments will cause a target to be perceived in a location other than its actual position. Results showed that fixation disparity (or heterophoria) cannot be used to predict the size or location of spatial errors; however, there was a trend toward longer distance judgments after base out prism wear. Parallels are drawn between optometric and psychological literature regarding oculomotor posture and spatial judgments.

INTRODUCTION

Fixation disparity is a small error in foveal alignment of the two eyes that occurs during binocular viewing. The misalignment does not exceed the limits of Panum's fusional area, and the images are perceived as fused even though they fall on noncorresponding points of the retina. Clinically, fixation disparity has been considered to be an indication of binocular stress, or the effort required to maintain precise motor fusion (Sheedy, 1980). In recent literature it has been described as a purposeful error which serves to increase the stability of the fusional vergence system by providing a stimulus to maintain steady-state convergence (Schor, 1979b).

The present study investigates the hypothesis that errors in spatial localization may be related to fixation disparity, i.e. misalignment in the lines of sight may cause an object to be perceived in a location other than its actual position. The perceived location of the object is defined by the intersection of the primary lines of sight, as shown in Fig. 1:

Insert Fig. 1 Here

Hypothetical Errors: OU Eso - Short OU Exo - Long

A stüdy by Fronk and Coffey (1986) examined this hypothesis in a group of skilled golfers, and found no relationship between putting errors and habitual fixation disparity. The authors suggest that, over time, compensation may occur for perceptual errors associated with fixation disparity, especially in frequently performed tasks which demand accurate spatial judgments. The current investigation differs from the above study by examining the spatial effect associated with induced fixation disparities (induced by prism wear) rather than <u>habitual</u> fixation disparities.

Various studies, while not specifically addressing fixation disparity, have described changes in perceived distance subsequent to manipulation of the binocular vergence system. In general, two methods have been used to obtain these changes, an induction paradigm and an adaptation paradigm. The induction method involves sustained fixation of a target at various distances. The distances may be actual or optically generated. In one such experiment, Ebenholtz and Wolfson (1975) used a mirror stereoscope to simulate presentation of luminous targets at distances from 16 cm. to 1.5 m. Distance estimates were recorded before and after six minutes of sustained viewing. After the induction period, they found subjects over- or underestimated distances depending on the given convergence distance, and that the shifts in perceived distance fit a linear function. A later study by Paap and Ebenholtz (1977) replicated these findings using wedge prisms rather than a mirror stereoscope to manipulate the inducing convergence positions. Ebenholtz and his coworkers maintain that these changes in distance perception are a result of a continued reflexive innervation of the extraocular muscles in the direction of the previous stimulus, an explanation known as the muscle potentiation theory. According to this theory, the extraocular musculature associated with convergence becomes potentiated during prolonged convergence tasks, and so requires reduced innervation to maintain the vergence posture. In order to continue fixation of a given object, an equal and opposite amount of voluntary muscular innervation would be required to overcome the reflexive potentiation, and eye position information based on monitoring voluntary motor signals will be erroneous. The information will be in error to the degree that the residual muscle tension, or potentiation, must be counteracted. As a corollary, any spatial dimension contingent on eye position information will be altered in a manner consistent with the registered eye position. Therefore, changes in perceived distance would be expected to be associated with maintaining the eyes in a fixed vergence posture. Specifically, sustained viewing of nearby targets would generate reflexive convergence, voluntary divergence, and greater perceived distances, while continued viewing of distant targets would generate reflexive divergence, voluntary convergence, and smaller perceived distances.

The second method that has been used to obtain changes in perceived distances is the adaptation paradigm, in which subjects wear spectacles which combine prism and a spherical lens power to force a corresponding change in accommodation and convergence. Wallach and his associates (Wallach & Frey, 1972; Wallach, Frey & Bode, 1972) performed a series of experiments in which subjects wore five prism diopters base out combined with -1.50 D lenses for 10-15 minutes, or five prism diopters base in combined with +1.50 D lenses. Wearing the base out spectacles resulted in an increase in perceived distance after prism removal, while the base in spectacles produced a decrease in perceived distance. The authors interpreted these results as a recalibration of oculomotor cues to distance. According to their theory, prism and lens combinations cause a discrepancy between the oculomotor cues to distance provided by convergence and accommodation and monocular cues like motion parallax and linear perspective. The cue conflict initiates a process of perceptual learning in which the cue function of the oculomotor system is reprogrammed to ally more closely with the remaining cues. Thus a given magnitude of convergence and accommodation comes to represent a greater or lesser distance than it signaled before the cue conflict occurred. If, for example, an object is viewed through lenses and prisms at an optical distance closer than the actual distance, oculomotor cues begin to signal increased distance after recalibration, and distance perception shifts toward the true distance. Proponents of the recalibration theory did not consider the possibility that the spectacles used to alter distance cues also may have had hysteresis effects on the oculomotor system, i.e. induced an eye position bias, or phoria, which could account for changes in distance perception.

A study by Ebenholtz (1981) was the first to measure changes in phoria concomitantly with changes in perceived distance. For comparison, both the adaptation and induction methods were used to induce phorias. In both conditions, greater perceived distances corresponded with a significant shift toward esophoria. The distance aftereffect of the adaptation condition was markedly greater than that obtained in the induction condition, and the ratio of distance changes was virtually identical to that of the changes in phoria obtained in the two conditions. These findings support a strong relationship between induced phoria and changes in distance perception.

As the present study will investigate the spatial effects of fixation disparities induced by prism wear, it is appropriate to note that inducing a phoria also typically induces a fixation disparity in a direction opposite the phoria (Ogle, 1967; Schor, 1979a). Thus inducing esophoria simultaneously induces exo fixation disparity, and inducing exophoria simultaneously induces eso fixation disparity. In view of the relationship established in previous studies between distance aftereffects and induced phorias, these findings are congruent with the predicted spatial effects of the hypothesis under investigation, i.e. that induced exo fixation disparity will be associated with distance overestimation, and induced eso fixation disparity will be associated with distance underestimation.

Numerous researchers have established that the magnitude of prism induced fixation disparity decreases as the duration of binocular viewing through prism increases, indicating that an adaptation occurs (Ogle and Prangen, 1953; Mitchell and Ellerbrock, 1955; Carter, 1965; Ogle, 1967; Schor, 1979a, 1979b, 1980). Ogle and Prangen (1953) and Schor (1979a) have proposed that this adaptation is due to a slow fusional vergence mechanism which acts to relieve stress on a faster form of fusional vergence. They suggest that retinal image disparity triggers the fast mechanism to align the eyes, and the slow mechanism acts to sustain the new position. Fixation disparity is considered to be an error signal that stimulates the fast fusional mechanism to avert any decay in vergence posture (Schor, 1979b; 1980). As slow vergence activity increases, fast vergence activity decreases, as does the associated fixation disparity. The action, or output, of the fast mechanism is thought to be the stimulus that activates the slow mechanism (Carter, 1965). When stimulus disparity is removed, the vergence response due to the slow mechanism persists, and may be identified by prism adaptation effects. Several researchers have linked the slow vergence mechanism and associated prism adaptation to an increase in the resting level of tonic vergence as measured by the lateral phoria (Ogle & Prangen, 1953; Schor, 1979b; Ebenholtz, 1981). An induced phoria, then, represents adaptive change in tonic innervation of the extraocular muscles which manifests as a lag in vergence posture in the direction the eyes were last held. In compensating for an induced phoria, the fast fusional mechanism fulfills the same function as voluntary muscular innervation in the muscle potentiation theory. Reflexive muscular innervation described by the theory may be analagous to the elevated level of tonic convergence associated with the slow fusional mechanism.

In a recent discussion of the muscle potentiation theory, Ebenholtz and Fisher (1982) suggest that changes in the innervation level, or muscle tonus, of the oculomotor system act as cues to perceived distance. Erroneous distance perceptions are implicit in this concept, since the perceptual system does not separate the innervation required to compensate for the magnitude and direction of an induced phoria from the innervation stimulated by response to the target distance. Work by Owens and Leibowitz (1980) which showed proportional changes in perceived distance and measures of dark vergence posture after prism adaptation offers support for this model.

The present study investigates whether distance perception is related in any systematic way to the fixation disparities which are simultaneously induced by prism wear.

METHOD

The subject sample was composed of three first year optometry student volunteers. The sample size was small because subjects were required to devote significant time and effort attaining skill in performing the experimental task. First year students were chosen to avoid any familiarity with the theoretical effects of prism wear. All subjects had at least 20/20 Snellen visual acuity with habitual correction, and at least 88% stereopsis as measured by the ring targets on the AO Vectograph chart projected at six meters. For each subject, baseline distance fixation disparity, distance phoria, and sighting eye were measured, and fixation disparity curves were charted at 40 cm. and at six meters (Appendix A).

Lawn dart throwing was chosen as the experimental task, so that the results might have relevance to activities in the real world. To minimize mechanical errors, the subjects were required to achieve a 35% criterion level of accuracy, i.e. 35% of throws landing within the target hoop, before beginning the experimental phase of the study. Each subject was provided with a set of lawn darts for practice throwing at home, and several group practice sessions were conducted to monitor progress. To avoid development of a distance dependent skill during practice sessions, subjects were instructed to vary their distance to the target hoop continually from 12 to 20 feet. Subjects practiced an average of 12-15 hours spread over six weeks to meet the criterion level. They were paid $10 when they demonstrated achievement of the criterion level and an additional $15 on completion of the experiment.

Throughout the study, fixation disparities were measured with a device constructed by Kent Fronk for an earlier study of oculomotor posture and golf-putting (Fronk and Coffey, 1986). The instrument measures actual fixation disparity at six meters, rather than associated phoria as obtained with the AO Vectograph or the Mallet box. The instrument (Fig. 2) consists of a 36x28x8 cm. metal box covered by a translucent white plastic face plate with a circular opening in the center.

Insert Fig. 2 Here

The opening is blacked out except for two 3x60 mm. movable vertical slits which are separately polarized to create a biocular condition, and the box is illuminated from within by two five-watt incandescent bulbs. Acuity letters (20/40, 20/20, 20/15) on either side of the central opening provide accommodative control, and the margins of the opening provide a peripheral fusion lock. To maximize the magnitude of fixation disparity, foveal contours were omitted (Carter, 1964; 1980). At six meters, the visual angle of the central circle is similar in size (1.5 degrees) to the Disparometer, a device disigned to measure actual fixation disparity at 40 cm. (Sheedy, 1980).

There were three parts to the experiment: no prism, after prism, and with prism. In each part, subjects attempted 50 consecutive throws of the lawn darts at the target hoop. In the first part of the experiment, all throws were made with no prism in place. During the second part, subjects wore 12 diopter base out prisms equally split between the eyes for a 15 minute adaptation period, and began throwing after the prisms were removed. Five minutes of throwing alternated with five minutes of readaptation to the prism glasses until 50 throws were completed. Prior to the experiment, fixation disparity decay curves (Appendix B) were run on all subjects to observe the time course of declining disparity after prism removal. Five minute readaptation intervals were chosen to maintain an optimum level of induced disparity. In the third part of the experiment, all throws were made while wearing 12 diopter base out prisms. To standardize across conditions, subjects in the first and third parts also threw the darts in five minute intervals separated by five minute breaks. Measures of phoria and fixation disparity were made before and after each set ot 50 throws.

The experimental procedure took place outdoors on an area of the campus lawn in the lee of a building. The target hoop, a yellow plastic ring 40 cm. in diameter, was located six meters from the subject. To limit potential perceptual-motor compensation for inaccurate throws, an occlusion device which blocked the subjects' view of the target was used to exclude visual feedback. The device consists of a frame-mounted opaque nylon curtain which could be opened and closed mechanically. When open, the subject had full view of the target hoop, dart flight path, and surrounding area; upon dart release, however, the curtain was dropped, occluding all but the initial portion of the dart's path. Dart locations were measured in centimeters from the center of the target hoop using a polar coordinate system (Fig. 3), and the darts were removed from the target area before raising the occlusion curtain for a subsequent throw.

Insert Fig. 3 Here

EXPERIMENTAL PROCEDURE

Testing began indoors with measures of lateral phoria and fixation disparity at six meters. Phorias were measured using a Maddox rod and a wall grid centrally illuminated by a flashlight bulb. Subjects reported the position of the streak with the Maddox rod interposed first in front of the right eye, then in front of the left eye. The phoria was considered to be the mean of the two measures using eso=+, exo=- sign convention. Fixation disparity was measured in free space using the previously described instrument with polarized glasses. One slit was centered in the circular opening while the other slit was moved toward it first from the left, and then from the right. Subjects verbally reported when the slits appeared to be aligned. Two measures were taken with the upper slit centered while moving the lower slit, and two measures were taken with the lower slit centered while moving the upper slit. Slit separation was measured in millimeters and later converted to arc minutes. The fixation disparity was considered to be the mean of the four measures using the same sign convention as for the phoria.

Throwing began outdoors with each subject being permitted 12 practice throws at the target hoop without the occlusion curtain being dropped, followed by four practice throws with occlusion. After the practice throws, the no prism trial began with five minute throwing periods alternationg with five minute breaks until 50 throws were accomplished. After each throw, the dart location was measured from the center target hoop with the measuring device shown in Fig. 3, and recorded in centimeters and degrees. When the final throw had been recorded, a post-test phoria and fixation disparity were measured.

In the second part of the experiment, subjects wore 12 diopter base out prisms in glasses or as clip-on prisms over their habitual correction for a 15 minute adaptation period. During this time, they walked a designated course along hallways and up and down stairways in the College of Optometry building. At the end of the adaptation period, the prisms were removed, and phoria and fixation disparity were measured as soon as the subject reported the absence of diplopia. All subjects were diplopic for 3-6 minutes after prism removal. Subjects then threw darts for five minute periods alternating with five minute readaptation periods during which the prisms were reapplied as previously discussed. After 50 throws had been completed, phoria and fixation disparity were remeasured.

In the third part of the experiment, subjects again wore 12 diopter base out prisms for a 15 minute adaptation period, walking the same course through the building. Phorias and fixation disparities were measured through the prisms, and all throwing was performed with the prisms in place. As in previous trials, five minutes of throwing alternated with five minute breaks.

The total time for each testing and throwing trial, excluding initial prism adaptation periods, was 30-40 minutes for each subject, with the three trials running consecutively. Total elapsed time for the complete experimental procedure was approximately two and one-half hours per subject.

RESULTS

The findings revealed that in the no prism condition, subjects had fixation disparities ranging from .42 arc minutes in the eso direction to .71 arc minutes in the exo direction, with a mean of .24 arc minutes of exo disparity. Two subjects were .31 p.d. esophoric, and one subject was orthophoric. In the after prism condition, all subjects showed esophoria and eso fixation disparity. The mean fixation disparity was 5.25 arc minutes, and the mean heterophoria was .83 p.d. In the with prism condition, fixation disparities ranged from .07 arc minutes in the exo direction to .86 arc minutes in the eso direction with a mean of .55 arc minutes of eso disparity. Two subjects were orthophoric and one subject was .31 prism diopters exophoric. These findings are summarized in Table 1.

Insert Table 1

The throwing data was categorized into a long or short hemifield, using the polar coordinate system described earlier. In analyzing the fixation disparity data, each subject was assigned a predicted hemifield based on the direction of the disparity shown in each condition. In accordance with the hypothesis, throws by subjects with eso disparity were predicted to fall in the lower hemifield (short), while throws by subjects with exo disparity were predicted to fall in the upper hemifield (long). No predictions were made for fixation disparities less than .10 arc minutes.

In each condition, frequency of throws by all subjects to predicted and non-predicted hemifields was tested by chi square analysis to determine whether a reliable prediction based on fixation disparity could be made as to where the darts should land. The Student t-test was used to determine whether the amount of linear displacement, or error, from the center of the target was significantly different between the predicted and non-predicted hemifields. The statistics showed no significant relationships between frequency or linear error and fixation disparity in any condition ($p > .05$), except in the with prism frequency analysis. Chi square analysis of the with prism condition revealed the number of throws falling in the non-predicted hemifield was significant [$Chi^2(1)=7.92$, $p < .005$). Data for only two subjects was used in this analysis since one subject's fixation disparity was less than .10 arc minutes, and the significance found may be an artifact of the fewer number of subjects.

Spatial errors relative to the subjects' phorias were analyzed in a similar manner with parallel results. Based on a popular clinical belief (and contrary to the experimental literature), it was predicted that esophoria would cause distance underestimation (throwing short) and exophoria would cause distance overestimation (throwing long). Chi square analysis revealed no relationship between the direction of the phoria and frequency of throws to either hemifield, except in the with prism condition which was significant again in the non-predicted hemifield [$Chi^2(1)=10.34$, $p < .001$]. As before, only two subjects' data were analyzed in this condition, since one subject was orthophoric and no hemifield could be predicted. The Student t-test showed no relationship between the hemifield predicted by heterophoria and the magnitude of linear error ($p > .05$).

A two-way repeated measures ANOVA was performed to determine whether the overall linear deviation from the center of the target was significantly different between conditions or between subjects. For the purposes of this analysis, distance errors from both hemifields were combined in each condition using a short=-, long= + sign convention. Results of the ANOVA indicate that magnitude of distance error was significantly different between conditions [$F(2, 294)=17.3$, $p<.001$], and that the significance is found in the after prism condition, in which all subjects threw longer than in the no prism condition. Differences between subjects were also significant [$F(2,147)=137.5$, $p<.001$], as was the interaction between subjects and conditions [$F(4,294)=18.4$, $p<.001$]

DISCUSSION

The results in all conditions indicate that the darts fell in the hemifields without any consistent pattern, and that neither fixation disparity nor phoria can be used to predict in which hemifield more darts will fall, or even in which hemifield greater linear error will occur. These findings are in agreement with a previously mentioned study that examined the relationship between golf putting and oculomotor posture (Fronk & Coffey, 1986). However, the results of the present study extend to induced, as well as habitual, phorias and fixation disparities.

Although no reliable prediction of spatial error can be made from measures of oculomotor posture, there appears to be some association between oculomotor factors and spatial judgments in view of the trend toward longer throws in the after prism condition. All subjects were esophoric with eso fixation disparity after prism wear, which is puzzling at first, since Schor's work associates induced esophoria with exo fixation disparity. However, in contrast to the present investigation, Schor measured fixation disparity through the inducing prism. Schor's hypothesis would, in fact, predict esophoria with eso fixation disparity after prism removal. When the base out prisms are removed, the stimulus to converge is eliminated, but the convergence response due to the slow fusional mechanism persists, and is measured as esophoria. To regain fusion, the fast fusional mechanism stimulates the extraocular muscles to diverge, and eso fixation disparity is present as a stimulus to maintain the divergent posture. Therefore, the experimental results are in accordance with Schor's theory. The muscle potentiation theory would predict a similar scenario, in which there is residual involuntary muscular innervation to converge, and a compensating amount of voluntary innervation to diverge in order to recover binocularity.

The trend toward longer throws in the after prism condition agrees with the relationship between induced esophoria and longer distance judgments found by other researchers (Ebenholtz, 1981; Ebenholtz & Fisher, 1982; Shebilske, 1983). It should be pointed out, however, that in previous work testing distances were largely within one meter, while in the present study all testing took place at six meters. The experimental results also are in harmony with muscle potentiation concepts that suggest that erroneous spatial judgments can be derived from eye position information that is generated by the compensatory voluntary innervation of the musculature.

In the with prism condition, little change would be expected in the phoria and fixation disparity with respect to the no prism condition, since after 15 minutes of adaptation, the balance between the fast and slow fusional mechanisms would have been re-established. Empirically, phorias and fixation disparities measured through the prisms were found to be little different from the measures in the no prism condition.

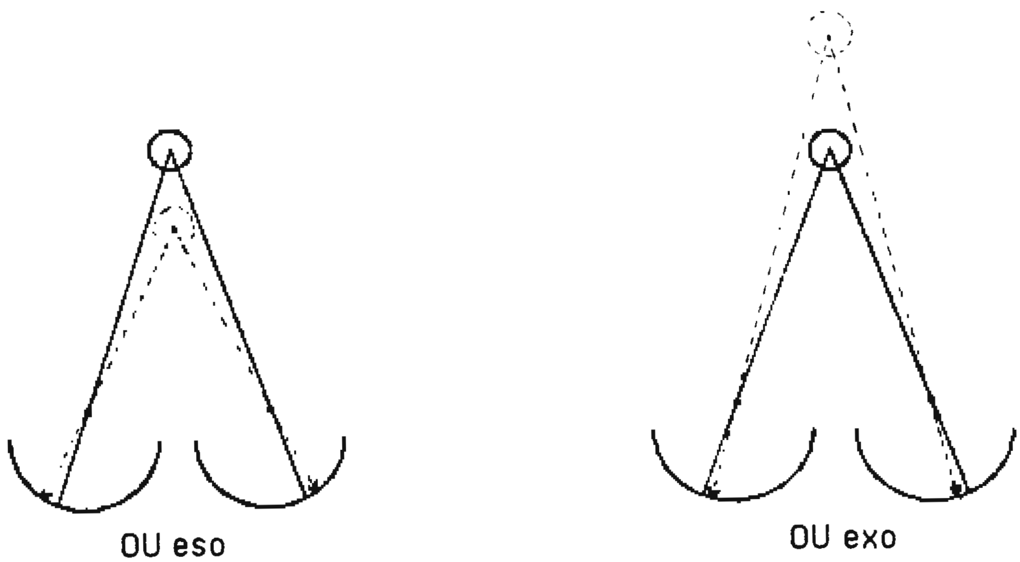
Altogether, the experimental data is more easily explained by the muscle potentiation or fast/slow vergence model than by the study's original hypothesis of fixation disparity as a predictor of spatial error.

According to the ANOVA, differences between subjects were significant, and an examination of Table 2 reveals large differences between individuals in the mean linear error in any given condition.

Insert Table 2

Presumably, this is the source of the interaction significance as well. The variance around these means, however, was found to be quite similar from subject to subject, which suggests the presence of an individual distance bias. Such a bias could be perceptual or motor in nature, and is beyond the scope of this study. On the other hand, it is interesting to speculate whether an individual distance bias could be related in some way to proposals made by Foley (1980) and von Hofsten (1976) concerning a reference egocentric distance or "set-point."

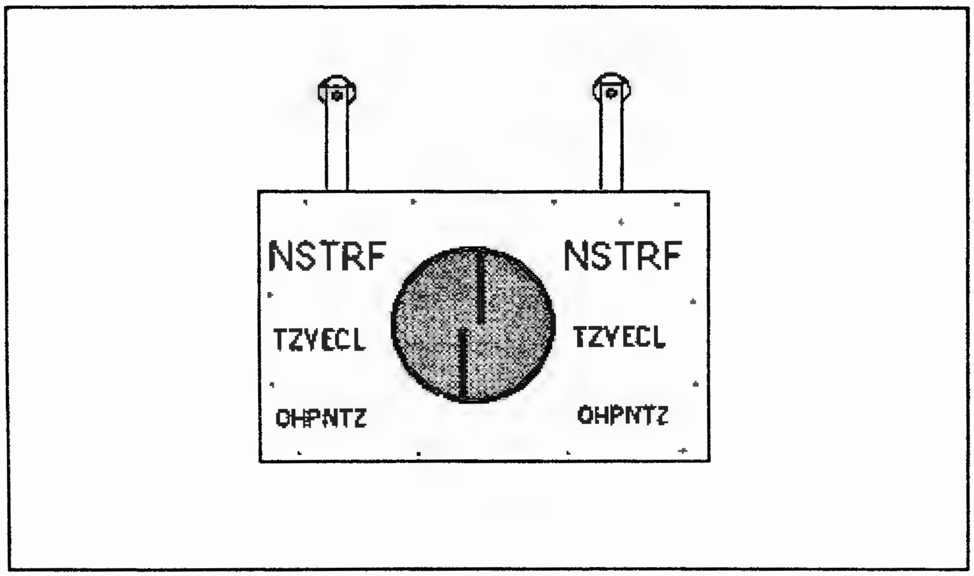
Figure 1



Hypothetical Error Due to Fixation Disparity

(from Fronk and Coffey, 1986)

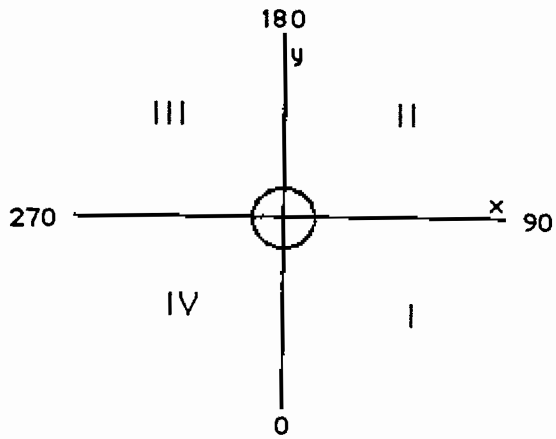
Figure 2



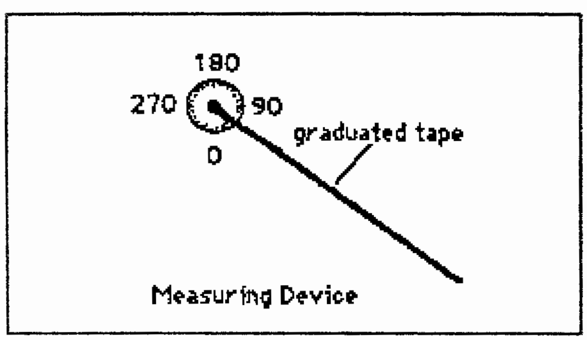
Fixation Disparity Device

(from Fronk and Coffey, 1986)

Figure 3



Polar Coordinate System



(from Fronk and Coffey, 1986)

Table 1

Subjects	No Prism		After Prism		With Prism	
	fd (arc min)	phoria (Δ)	fd	phoria	fd	phoria
J	-.71	.31	9.02	1.87	.86	0
SC	.42	.31	3.15	.31	.86	-.31
SM	-.43	0	3.58	.31	-.07	0

Measures of fixation disparity and heterophoria (exo=–, eso=+)

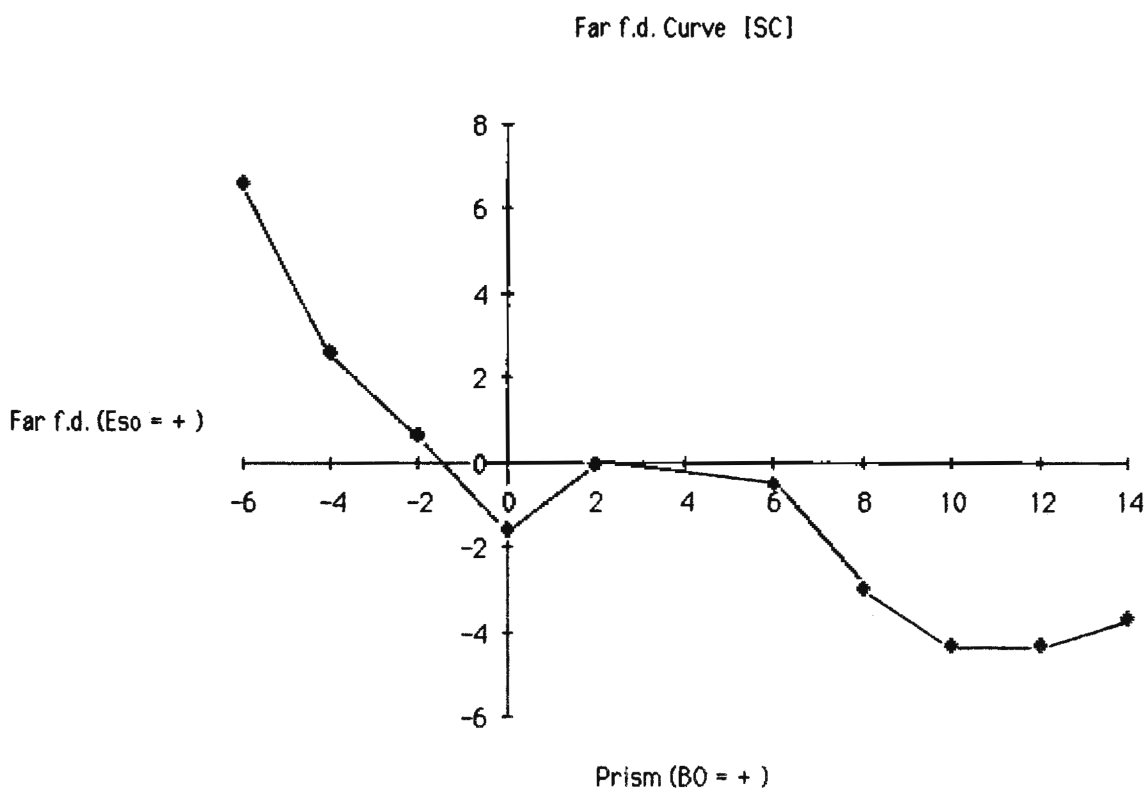
Table 2

Subjects	No Prism		After Prism		With Prism	
	mean	sd	mean	sd	mean	sd
J	-2.40	31.55	42.25	22.16	27.18	25.90
SC	-13.40	32.35	-12.64	34.08	-5.15	34.16
SM	-31.78	31.31	-19.65	32.96	-62.81	33.39
All Ss	-15.86	----	3.32	----	-13.59	----

Linear error in centimeters (short=-, long=+)

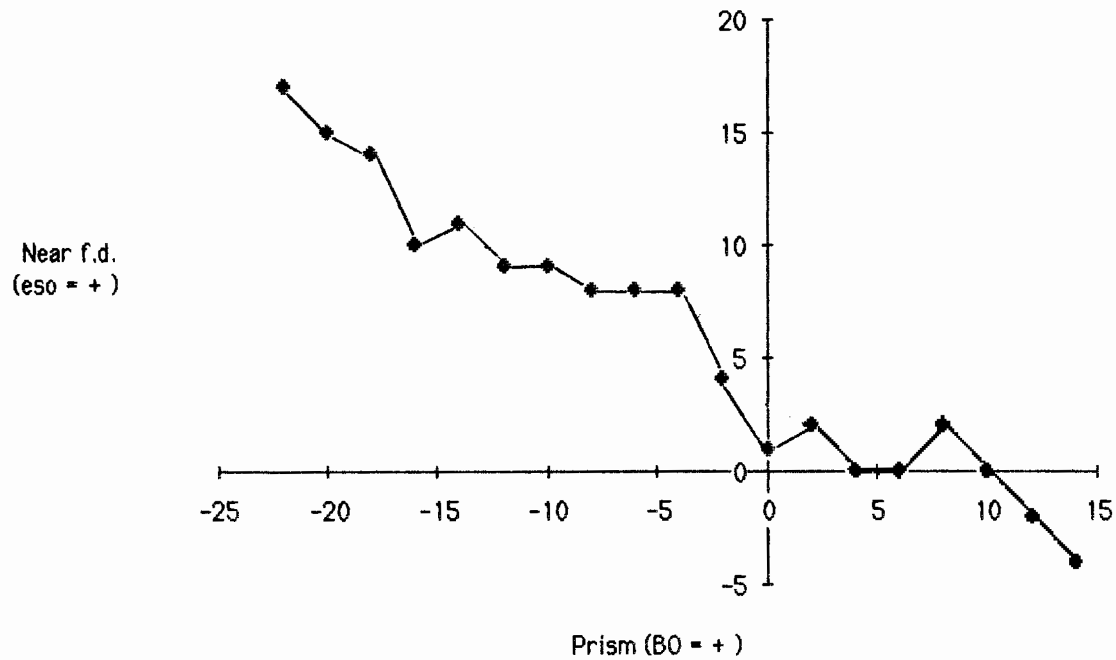
Appendix A: Forced Duction Fixation Disparity Curves

Appendix A



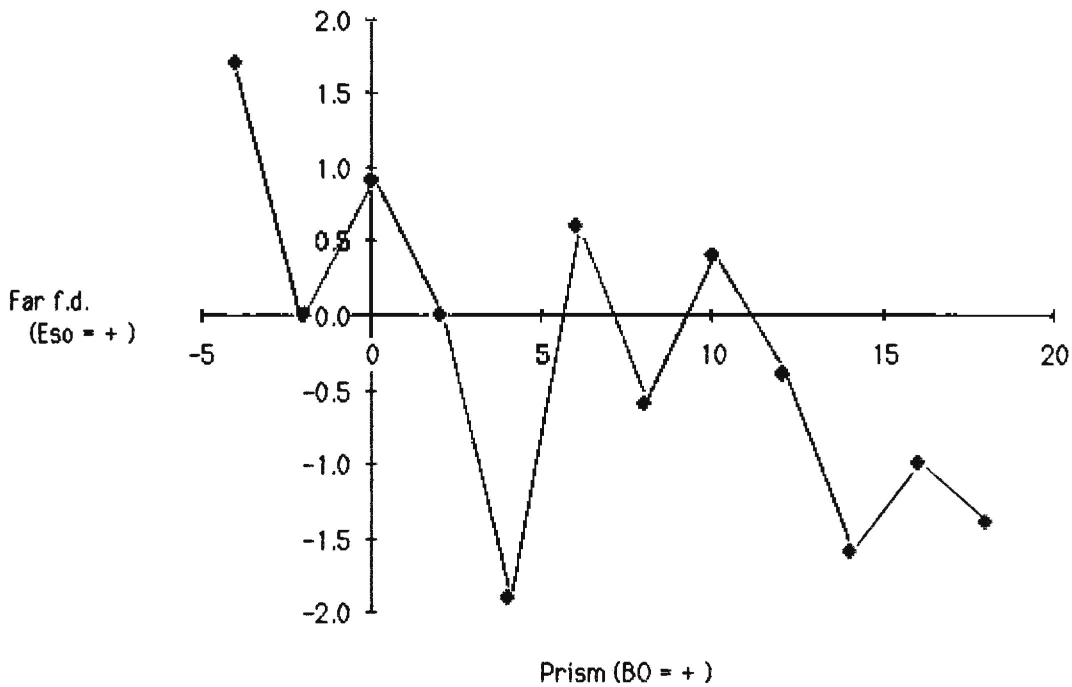
Appendix A

Near f.d. Curve [SC]

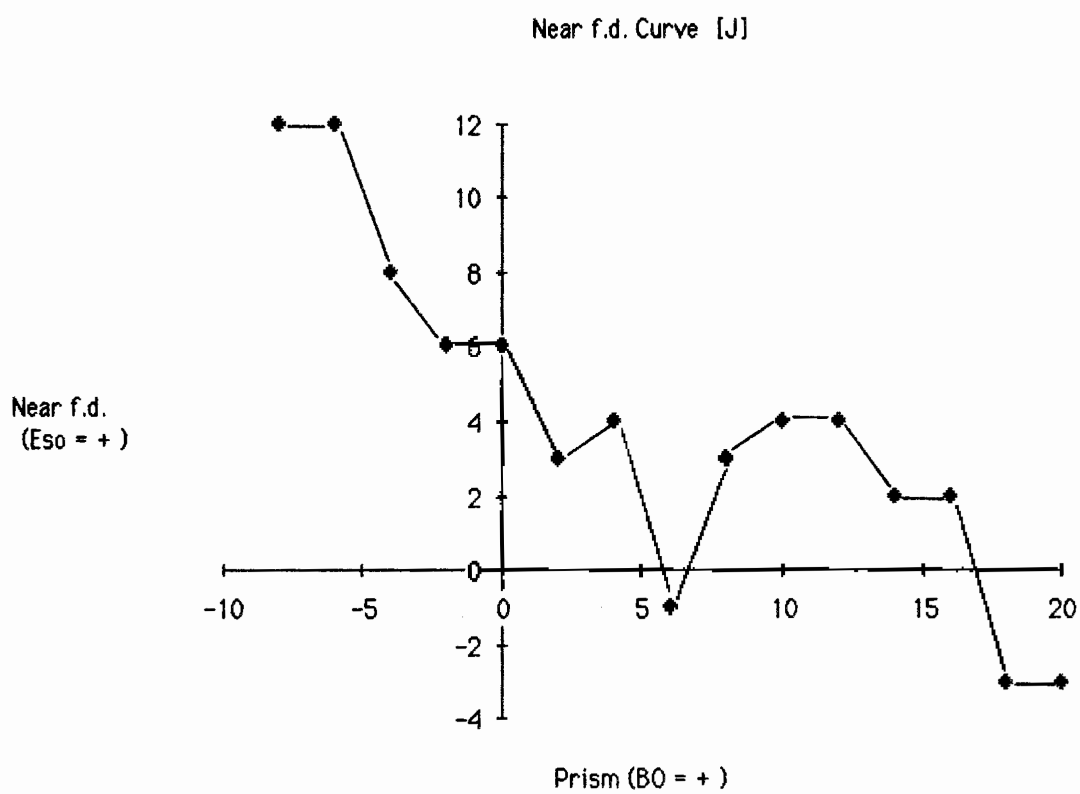


Appendix A

Far f.d. Curve [J]

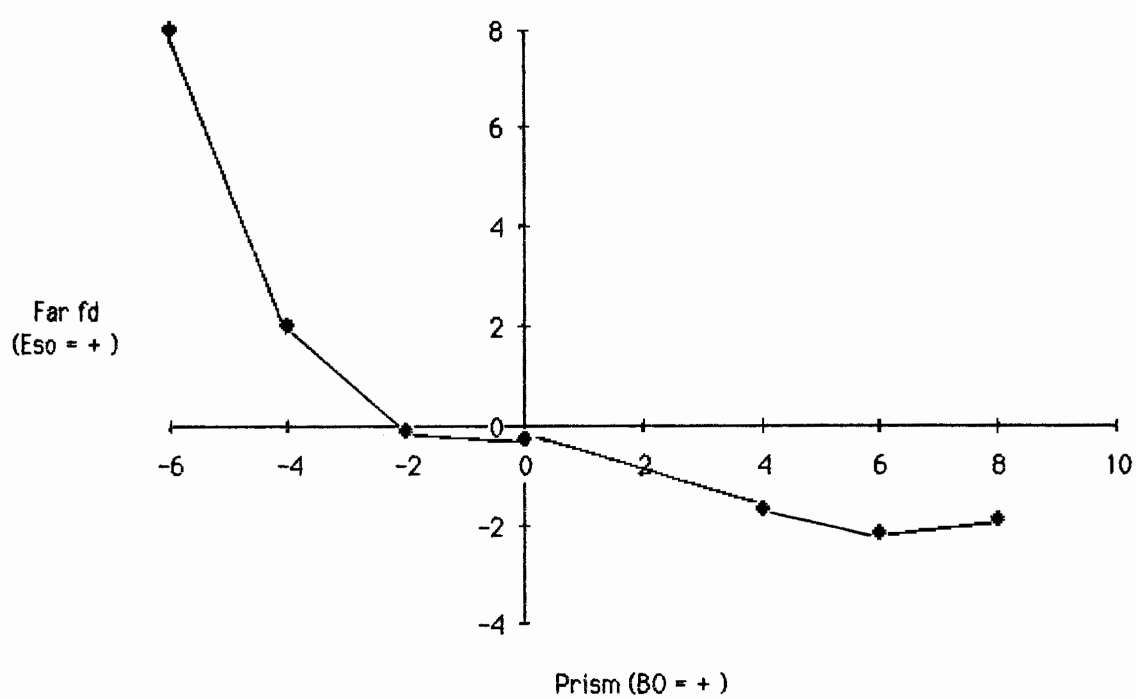


Appendix A


Near f.d. Curve [J]
Near f.d.
(Eso = +)
12
10
8
6
4
2
0
-2
-4
-10
-5
0
5
10
15
20
Prism (BO = +)

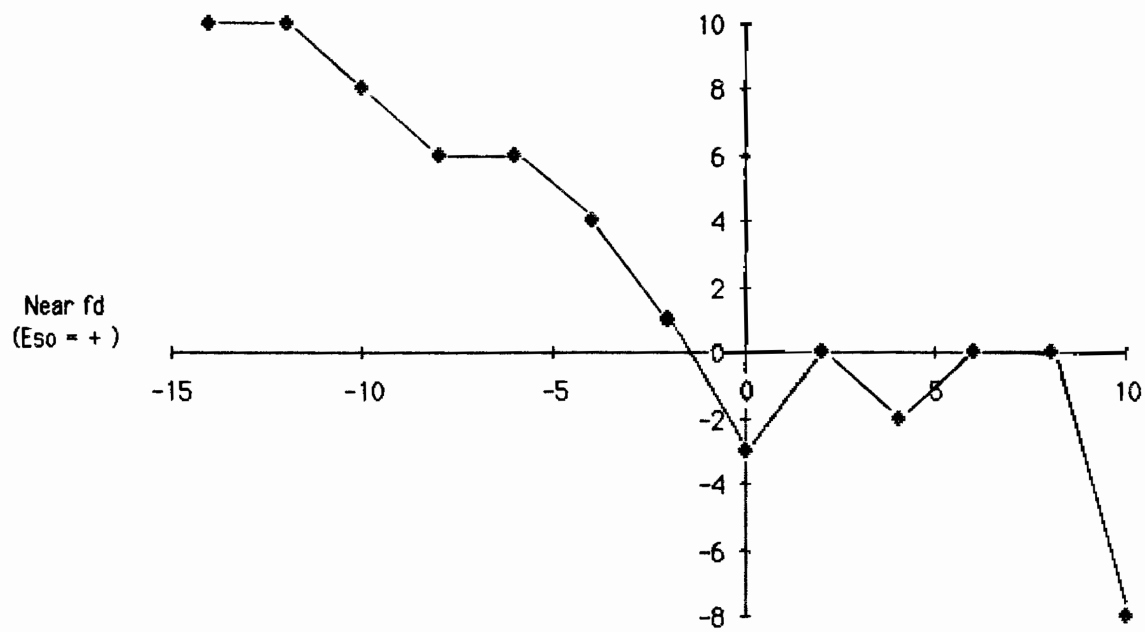
Appendix A

Far f.d. Curve [SM]



Appendix A

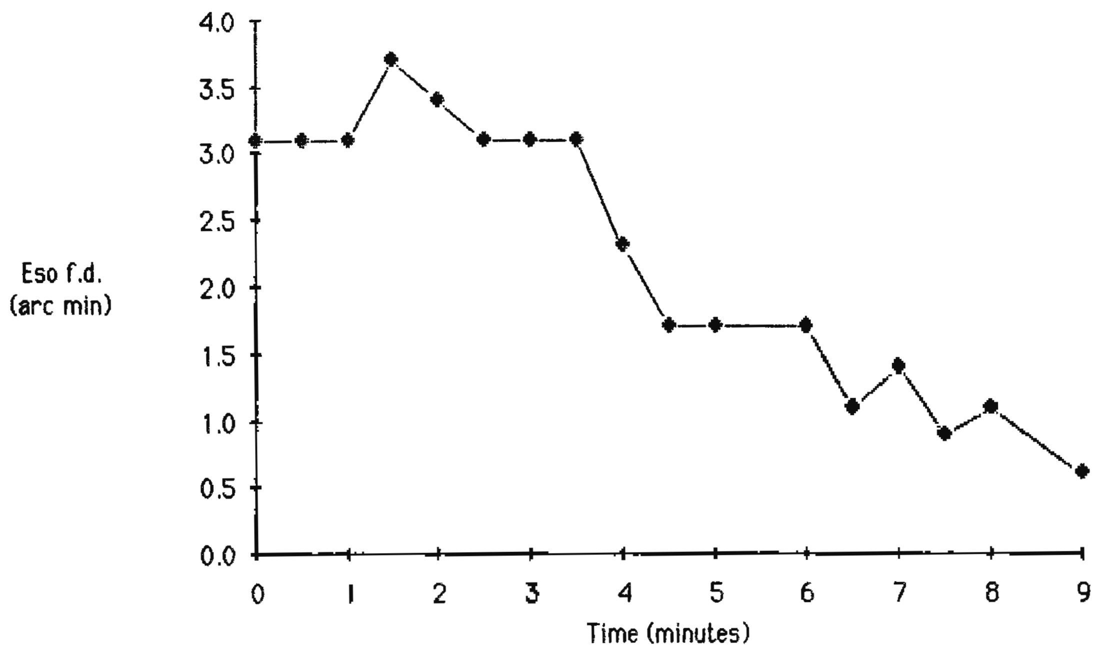
Near f.d. Curve [SM]



Appendix B: Fixation Disparity Decay Curves

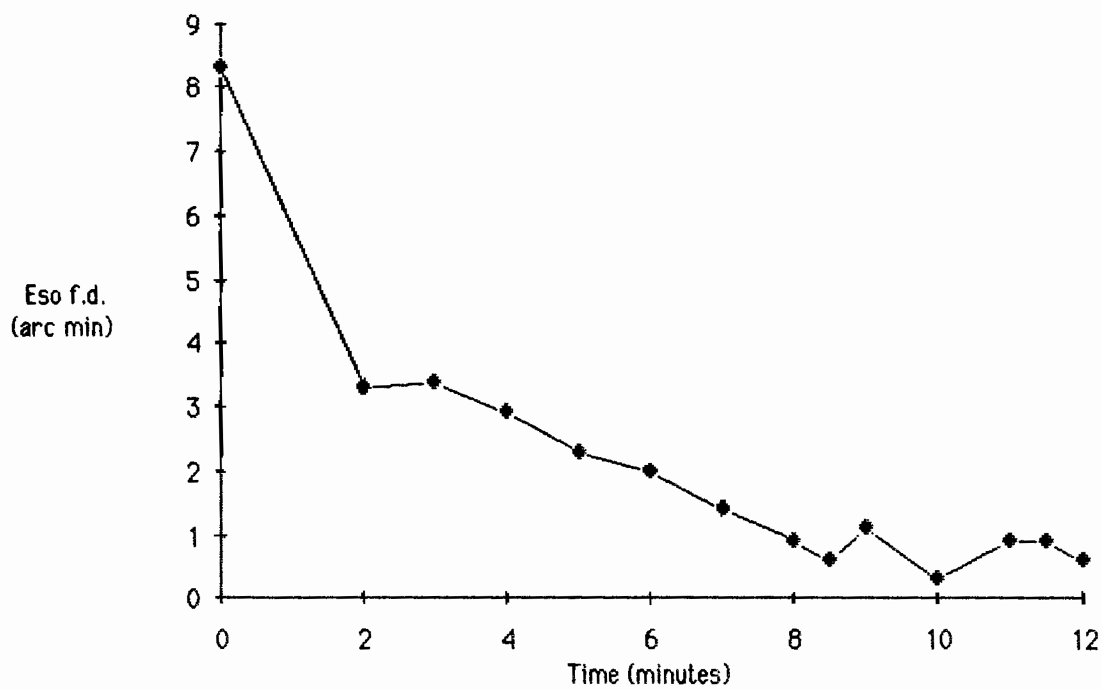
Appendix B

Decay Curve [SC]

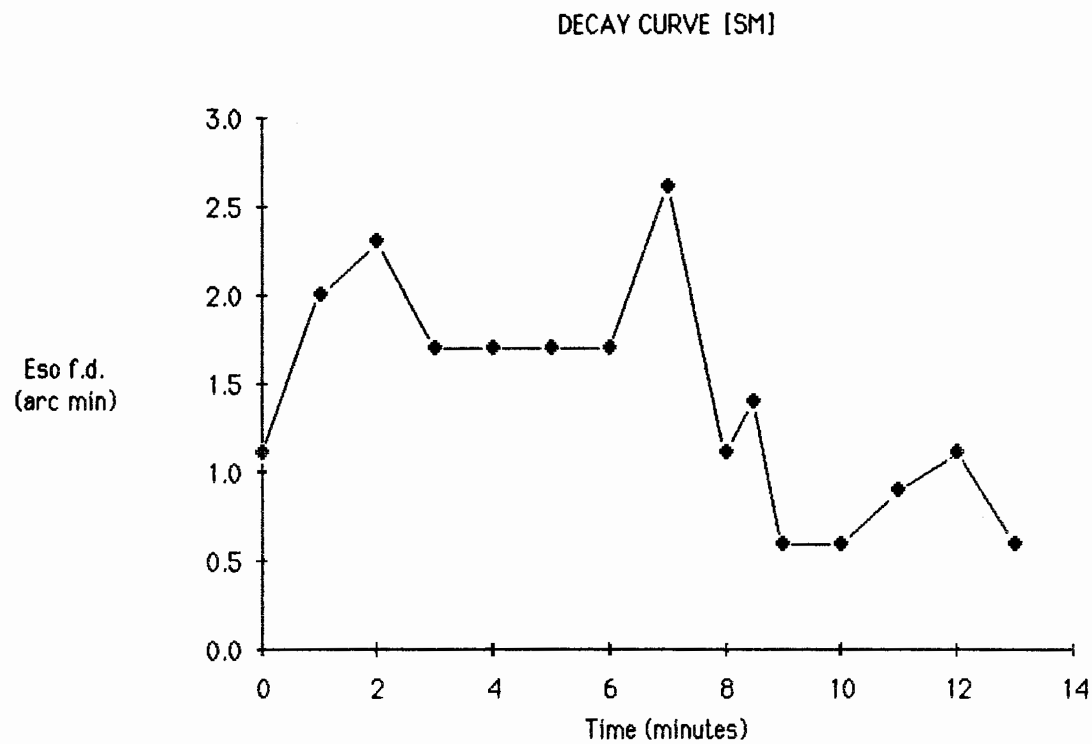


Appendix B

DECAY CURVE [J]



Appendix B



DECAY CURVE [SM]
Eso f.d.
(arc min)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
12
14
Time (minutes)

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