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Little research has been done to study the effect of anisometropia on the ability of subjects to localize an object in space using binocular depth cues. Rendering a patient artificially anisometropic is similar to prescribing an unbalanced refraction or inducing anisometropia in a monovision contact lens fit. We investigated the effect of induced anisometropia on stereolocalization. Spectacle lenses were used to create the anisometropic conditions and all subjects were pretested for isometropia while wearing their best distance refractive corrections. Thirty-eight subjects judged the distance of a floating vectographic Quoit's Ring target under varying amounts of anisometropia in a featureless field. The amounts of anisometropia induced ranged between 0.50 D and 1.75 D. The results indicate that there is no statistically significant difference in the ability to stereolocalize with up to 1.00 D of anisometropia, however, beyond this limit a statistically significant decrease in performance clearly exists.

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Paul Kohl

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THE EFFECT OF LENS-INDUCED ANISOMETROPIA ON STEREOLOCALIZATION

BY

DANIEL C. CRAWFORD AND MARK J. GLANZER

A thesis submitted to the faculty of the
College of Optometry
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Forest Grove, Oregon
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Advisor:
Paul Kohl, O.D.

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Daniel C. Crawford earned his Bachelor of Arts degree in Biology at the University of Colorado at Colorado Springs in 1990. He was graduated from Pacific University College of Optometry with a Doctor of Optometry degree in May 1994. After completing a residency program in family practice optometry at the University of Alabama, Birmingham, he plans to enter private practice in Colorado.

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Abstract:

Little research has been done to study the effect of anisometropia on the ability of subjects to localize an object in space using binocular depth cues. Rendering a patient artificially anisometropic is similar to prescribing an unbalanced refraction or inducing anisometropia in a monovision contact lens fit. We investigated the effect of induced anisometropia on stereolocalization. Spectacle lenses were used to create the anisometropic conditions and all subjects were pretested for isometropia while wearing their best distance refractive corrections. Thirty-eight subjects judged the distance of a floating vectographic Quoit's Ring target under varying amounts of anisometropia in a featureless field. The amounts of anisometropia induced ranged between 0.50 D and 1.75 D. The results indicate that there is no statistically significant difference in the ability to stereolocalize with up to 1.00 D of anisometropia, however, beyond this limit a statistically significant decrease in performance clearly exists.

Key Words: stereolocalization, anisometropia, depth perception, monovision, crossed/uncrossed disparity

Introduction:

It is well-known that binocularity increases the ability of an individual to accurately perceive depth, provided the individual possesses stereopsis (third-degree fusion). What is less well understood is the role that unequal refractive error plays in affecting the ability of those who have some level of stereopsis to accurately judge where an object is in space. This ability we refer to as stereolocalization, and is distinguishable from stereoacuity. Stereoacuity is defined as "the ability to perceive depth by the faculty of stereopsis, represented as a function of the threshold of stereopsis."[1] Stereolocalization is the term used to describe where in space an object is perceived to be by a subject's visual system, when using binocular cues provided by retinal disparity.

We chose to limit our investigation to the effects of anisometropia on central stereopsis. Since the target subtended a visual angle less than 5 degrees, it is considered a central target. The target size selected was approximately the size of a softball viewed at a distance of one and one-half meters. This distance is typical of that involved in such common activities as bending down to pick something off the floor.

This study does not deal with dynamic stereolocalization, as our target and our subjects were stationary during testing.

While not many works on the effects of anisometropia on stereolocalization have been published, quite a number have been written on anisometropia and stereopsis. In their study comparing "Stereopsis in Presbyopes Wearing Monovision and Simultaneous Vision Bifocal Contact Lenses", McGill and Erickson reported that stereopsis was no worse in monovision wearers than it was in those wearing simultaneous vision bifocal contact lenses.[2] Kastl, who studied stereopsis in those wearing monovision contact lenses, concluded that subjects retained a fairly high degree of stereopsis (50 arcseconds, on average) despite the induced anisometropia inherent in monovision.[3] Weidt and Cunin state that "stereoscopic vision does not seem to be affected by monovision wear."[4]

The area of stereolocalization itself has not received much attention in the literature to date, especially with respect to its relationship to anisometropia. Bleything found that minus and base-out lenses had the effect of increasing the distance of stereoscopic float from the observer.[5] Frederickson and Gorham conducted a thesis study at Pacific University in which they found that subjects' stereolocalization was accurate to within one percent of the predicted float for a vectographic target under both crossed and uncrossed disparity conditions.[6] They also reported that subjects were slightly more accurate at stereolocalization with two uncrossed disparities than they were with the corresponding crossed disparities.[7] Knight and Johnson, in another study at Pacific, wrote that "the idea that stereolocalization is affected by refractive status gets no support from this study."[8]

It was into this area of scant research that we ventured with our clinical trial study on the effects of lens-induced anisometropia on stereolocalization.

Subjects were chosen who had no more than 0.25 diopter of anisometropia when wearing their habitual corrective lenses. It was through the use of lenses that we induced unequal refractive conditions in our subjects. We chose the lenses necessary to induce anisometropia in our subjects in accordance with the amounts of anisometropia commonly prescribed for monovision contact lens wearers. We hoped to gain information concerning the degree to which stereolocalization is changed in these patients. Our hypothesis was that an individual's ability to stereolocalize would progressively deteriorate when subjected to increasing amounts of induced anisometropia.

Methods:

Our study consisted of a laboratory trial involving 38 subjects, most of whom were optometry students ranging in age from 20 to 40 years old. Subjects participated in an experiment in which they wore polarized glasses and viewed a suspended Stereo Optical

Quoit's Ring vectogram. The vectogram, which measured 9.3 cm in diameter, was set at three different disparities, corresponding to 1.2 prism diopters base-out (crossed disparity), 1.2 prism diopters base-in (uncrossed disparity), and ortho (zero disparity).

When viewing the Quoit's Ring set at a crossed disparity, the normal viewer will see two separate rings (see Figure 1), unless polarizing filters are worn over each eye. The polarizers are oriented differently between the two eyes by 90 degrees. While the subject's right eye sees the ring on the subject's left, the left eye sees the ring on the right, and the brain fuses the two images to form a single one which appears to float closer to the subject than the ring actually is. Under conditions of uncrossed disparity, the subject's right eye sees the ring on the subject's right, and the left eye sees the ring on the left, creating for the subject a single image which appears to float farther away from the point where the ring actually is.

At zero disparity, the Quoit's Ring subtended 3.55 degrees of arc when viewed by subjects at a distance of 1.5 meters (see Figure 2). Underneath the suspended vectogram lay a straight track of 2.46 meters length, on which a small cart could be wheeled toward or away from the subject, who sat at one end of the track. We tried to minimize monocular depth cues by surrounding the apparatus with a blank white field. We accomplished this by draping white sheets around both the sides and the end of the apparatus. The cart was designed so that the experimenter could control its movement by drawing on a string which was connected to the cart via a series of pulleys. The subject was instructed to indicate verbally when a vertical peg on the moving cart came directly under the point where the perceived fused target appeared to be floating.

It is a well-known phenomenon that as a subject responds to a base-out demand, the object viewed appears smaller and closer, whereas with a base-in demand, the object seems larger and farther away. This is called the SILO effect (Smaller In Larger Out).[9] In order to maintain a relatively constant separation between the top of the peg and the subject's perception of the bottom of the "floating" Quoit's ring (the measured separation when the peg was directly beneath the ring was 3.5 cm) a series of gears within the cart drove the peg upwards as the cart moved toward the subject, and downwards as the cart moved away from the subject.

All subjects were required to pass three entrance tests prior to participation in the experiment. First, the modified Wirt circles test (part of the Titmus Stereo Tests) was administered while the subjects wore polaroid filters over their habitual refractive corrections. The passing criterion was 100 arcseconds of stereoacuity. The second screening test required the subjects to maintain a single image when viewing a fixation bead through both eight prism diopter base-in and eight prism diopter base-out lenses at a distance of approximately forty centimeters. Third, we quantified the subjects' existing anisometropia by testing monocular negative relative accommodation. Subjects were required to have no greater than 0.25 diopter of anisometropia in order to participate in our study. We then measured subjects' interpupillary distances at forty centimeters and at infinity using a penlight and millimeter rule. We determined subjects' dominant eyes by having them sight a small distant object through a hole held at arm's length.

A random sequence of lens presentations to each subject was obtained in a double blind manner. The spherical lens powers used were: plano (control), +0.50 diopter, +1.00 diopter, +1.50 diopters, and +1.75 diopters. For each subject, we placed a loose trial lens in a lens well incorporated into a pair of polaroid glasses that the subject wore. The subjects wore their distance corrections throughout the trials. The loose lens was always placed over the subject's dominant eye.

The subject's head rested in a chinrest immediately behind a screen (see Figure 3). The Quoit's ring vectogram was suspended by clear nylon filaments at a distance of 1.5 meters from the screen through which the subject looked. We used three different vergence demands for the Quoit's ring: 1.2 prism diopters base-out (crossed disparity), zero prism diopters, and 1.2 prism diopters base-in (uncrossed disparity). We presented each subject with the crossed disparity condition first. We obtained three readings for each of the five different lenses used. The second and third trials involved zero disparity and uncrossed disparity, respectively, conducted in similar fashion to the first. A total of forty-five measurements were recorded per subject.

We instructed each subject at the beginning of testing to verbally indicate when the moving peg, which the experimenter manually controlled by drawing on the string attached to the cart, was positioned directly underneath the floating ring. We told subjects to modify their responses, if necessary, by telling us to move the cart slightly forward or backward after their initial response.

RESULTS:

The data was collected in the form of a measurement of the distance from the plane of the vectographic target to the position that the subject perceived the rings to float, in centimeters. Since a centimeter at 40 cm represents a different prismatic convergence demand than a centimeter at 100 cm, we converted all of the data into meter angles (MA). Once converted, comparisons of float position produced by each lens change could be made because of the equal convergence demand units (MA), of all values. The average of the three readings per lens per disparity condition was used for analysis.

To begin the analysis, we looked at the data using descriptive statistics to find out how each lens change of induced anisometropia affected the subjects' ability to stereolocalize. The central tendency of our data was described by the mean of the difference between the theoretical value (the point where the subject should have perceived the float based on calculations using interpupillary distance, target separation, and target distance) and empirical value (the actual point where the subject perceived the rings to float). To derive theoretical float we used similar triangle ratios (see Figure

4). This allows us to tell if the subjects are localizing more accurately or less accurately with each lens change. A larger mean difference value indicates that the subjects are localizing the target further from the theoretically determined value. A smaller difference indicates that the subjects are localizing the target closer to the calculated theoretical value. The results indicate a trend of greater inaccuracy (usually an underestimation of the float effect) with greater anisometropia for both crossed and uncrossed disparity conditions. The condition of ortho disparity shows no significant difference with increasing anisometropia. We can also look at these mean difference values as percentages. The percent difference was less than 0.7% for all lenses for the zero disparity trials (see Figure 5). For the base-out disparity condition, the plano lens caused an inaccuracy, in meter angles, of 2%. This increased to almost 5% for the 1.50 D and 1.75 D lenses (see Figure 6). For the uncrossed condition, the plano lenses caused a 1.5% error in localization which increased to 3% for the 0.50 D and 1.00 D lenses. A 4% error was attributed to the 1.50 D lens and the 1.75 D lens produced the largest amount of error, at 10% (see Figure 7).

To find out if this tendency was statistically significant we ran a repeated measures ANOVA on the differences for each lens condition. This test revealed that the accuracy of judging float was reduced by a statistically significant amount, as is demonstrated by a P value of 0.0001. We then ran a post hoc Scheffe F-test to reveal which of the lens conditions were statistically different from the others. At a 90% significance level, this test quite dramatically shows that in the 1.50 D and 1.75 D trials, the ability to stereolocalize is reduced by a significant amount when compared to the plano, 0.50 D, and 1.00 D conditions. This result exists for both the crossed and uncrossed test conditions. The 1.50 D and 1.75 D lens conditions were not significantly different from each other for both crossed and uncrossed conditions. Since we did not run any subjects with 1/8th diopter incremental changes, and since we did not test with 1.25 D of anisometropia, we cannot report the precise point beyond which induced anisometropia significantly impairs stereolocalization. But we can estimate it to be somewhere between 1.00 D and 1.50 D.

Discussion:

Analysis of our data indicates that under the testing conditions described, higher amounts of anisometropia decrease the amount of "float" perceived by subjects under both the crossed and uncrossed disparity conditions. It is evident that induced anisometropia of greater than one diopter significantly impairs accuracy of stereolocalization.

Our original hypothesis was that the ability to accurately stereolocalize a floating target would be degraded with increasing amounts of induced anisometropia. This proved true in our experiment, both in the actual data and in the subjects' casual comments during the trials. Many stated that with the highest power lens used, they attempted to ignore and suppress the grossly blurred image of the fogged eye. Yet in order to appreciate stereopsis, two disparate retinal images had to be perceived.

The results indicate that there is no statistically significant difference in the ability to stereolocalize small targets when up to one diopter of anisometropia is induced. However, beyond this amount, a statistically significant decrease in performance clearly exists. The clinical significance of this decreased capability needs to be addressed. With either 1.50 D or 1.75 D of induced anisometropia, a statistically significant 5% meter angle difference in performance was produced by the crossed disparity conditions, which translates into a linear error of 7.5 cm in localizing small targets at 1.5 meters. For uncrossed disparities, a 4% error, as seen in the 1.50 D trial, translates to 22.2 cm and the 10% error in the 1.75 D case results in 32.4 cm of linear error at 1.5 meters. This degree of inaccuracy could have a significant impact in one's daily activities. It should be pointed out that even in the zero disparity condition, subjects consistently perceived the ring to be slightly farther away from them than it actually was for all lens conditions.

During the experiment, several subjects mentioned that they were using a seam in the track to help them judge where the ring was positioned (in the zero disparity setting). The seam was slightly behind the actual ring position, relative to the subject, and may have caused the offset at the zero disparity condition.

There are many practical examples which demonstrate the need for accurate stereolocalization. Stereolocalization is involved in many household tasks, such as picking up fallen objects from the floor and reaching for items from a shelf. In the workplace, stereolocalization can be critical in such jobs as carpentry and machining. Athletics also provides examples where judging distances is very important. For example, in football, a quarterback needs to accurately judge distances to successfully complete a pass. In golf, the distance perceived from the golfer's hand to the golfball is critical. Also, to generate the most power in a tennis serve, the ball should be hit at the apex of the toss, requiring good localizing skills.

An application can also be made to contact lens monovision wear. Contact lenses worn to correct for presbyopia with anisometropia of greater than one diopter will create a significant difference in central stereolocalization performance.

In light of our results, practitioners concerned with central stereolocalization performance in their patients should be aware of the necessity of accurate binocular balance testing.

Further research is needed to establish more precisely the amount of induced anisometropia which significantly compromises central stereolocalization. Our findings should be duplicated in a contact lens monovision study in order to demonstrate the validity of our results for contact lens wearers.

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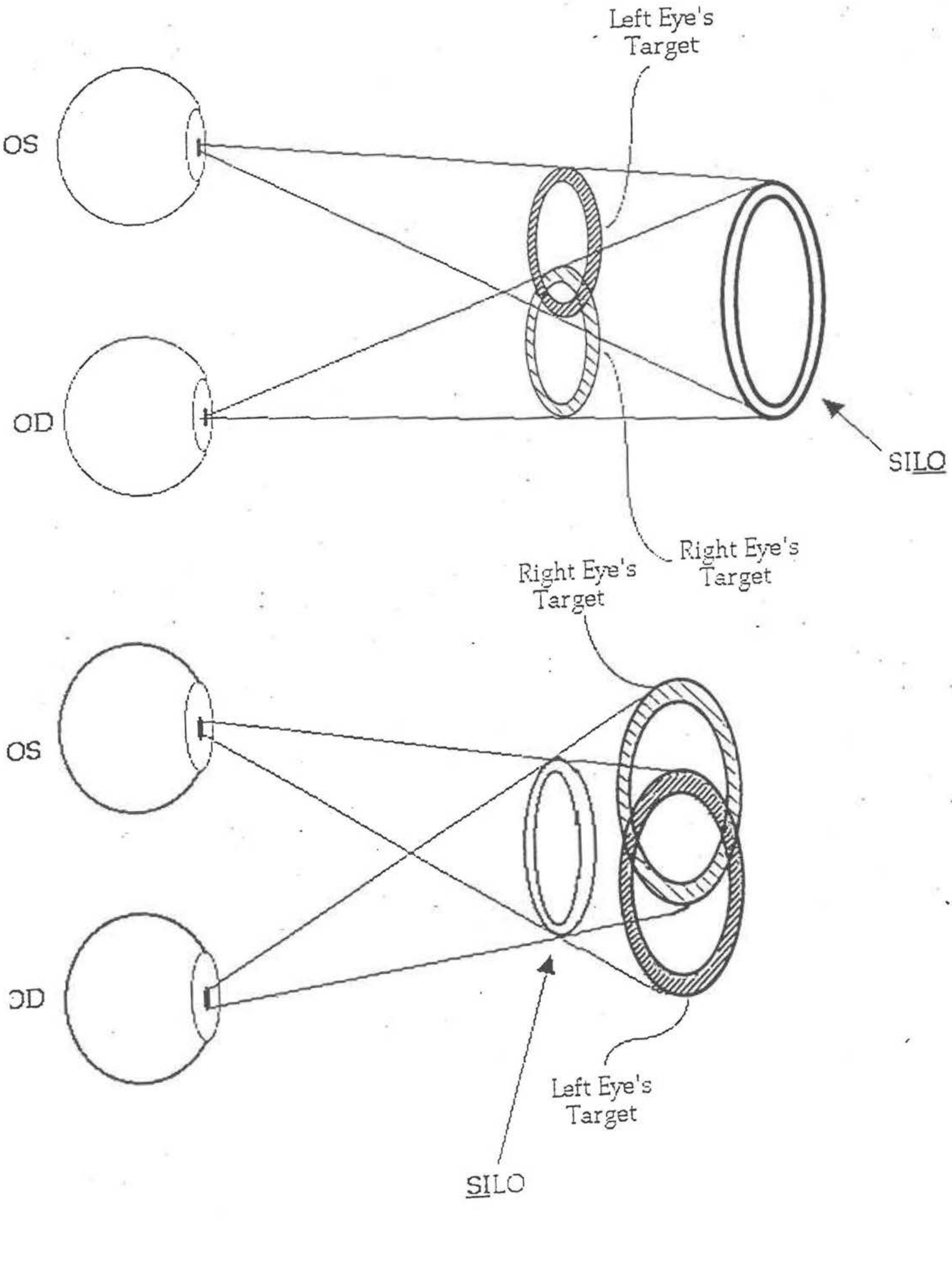


Figure 1: Vectographic Principles[10]

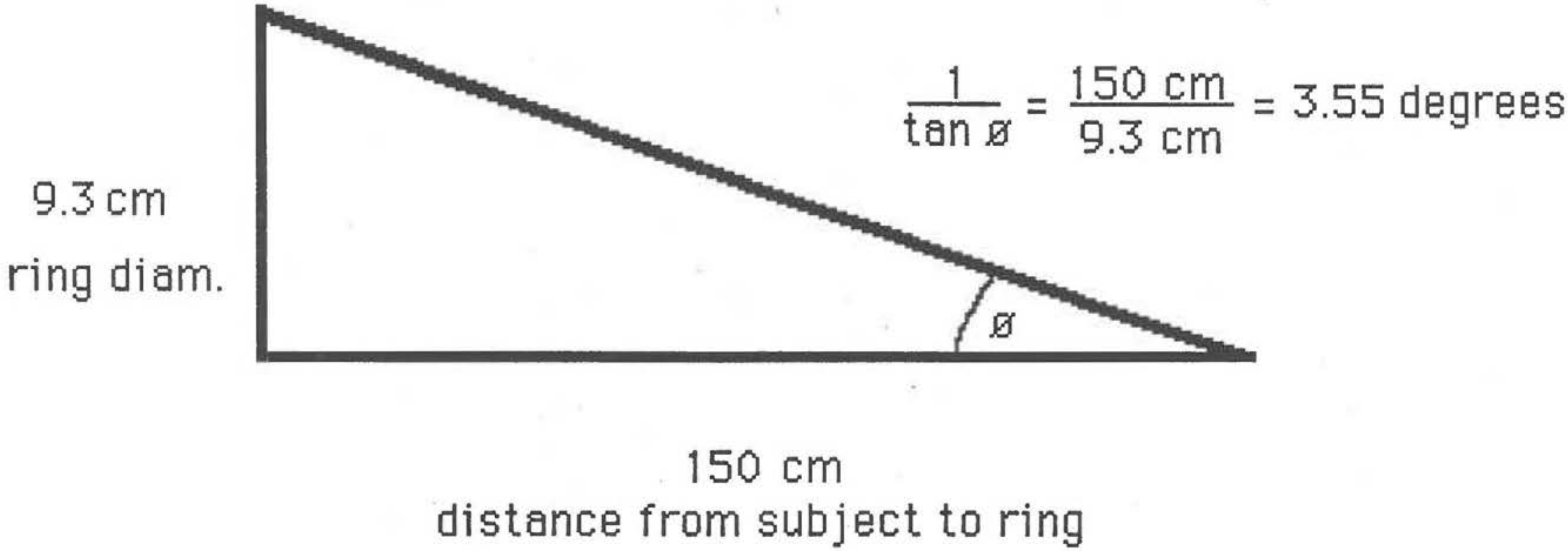


Fig 2: **Angular Subtense**

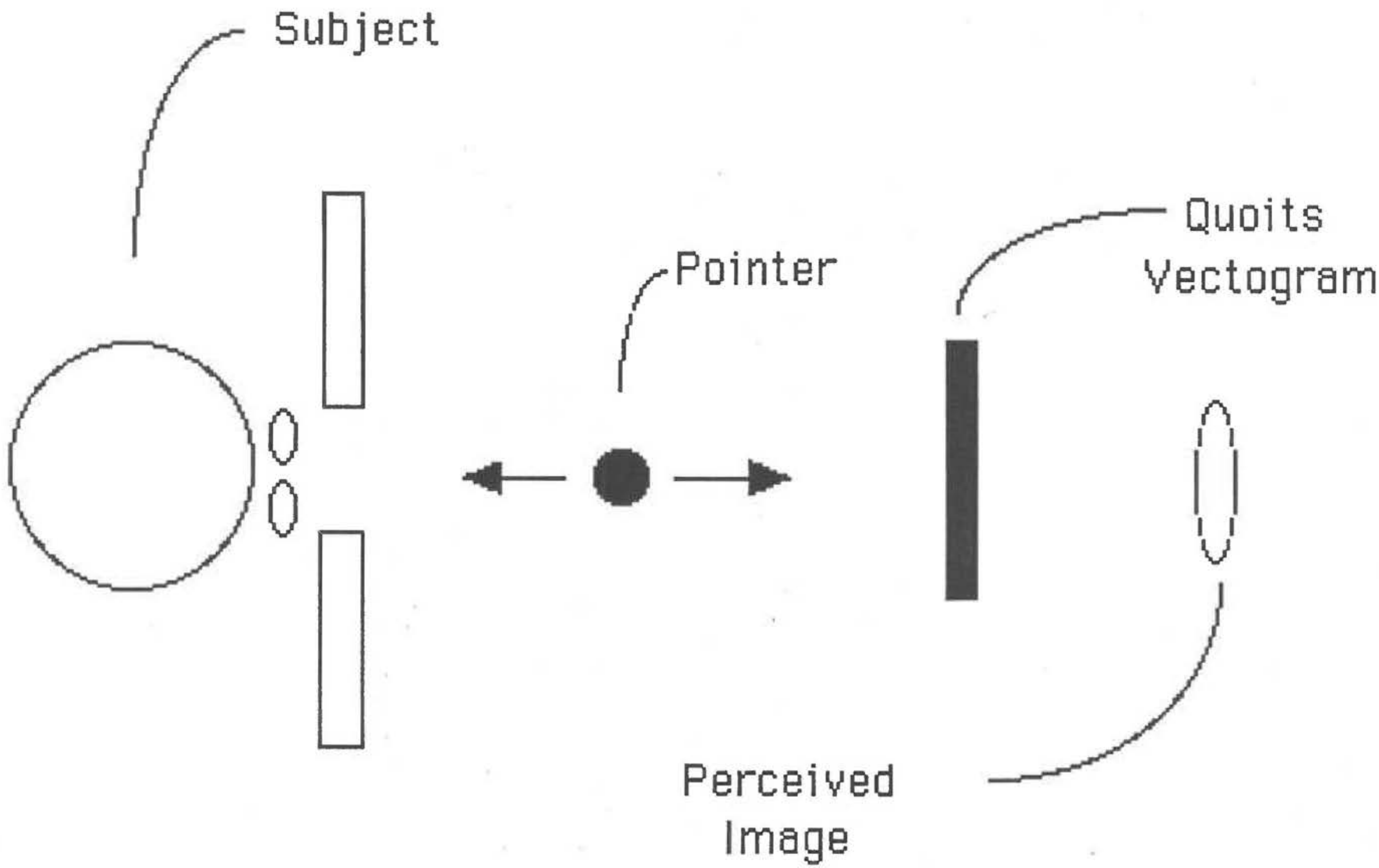
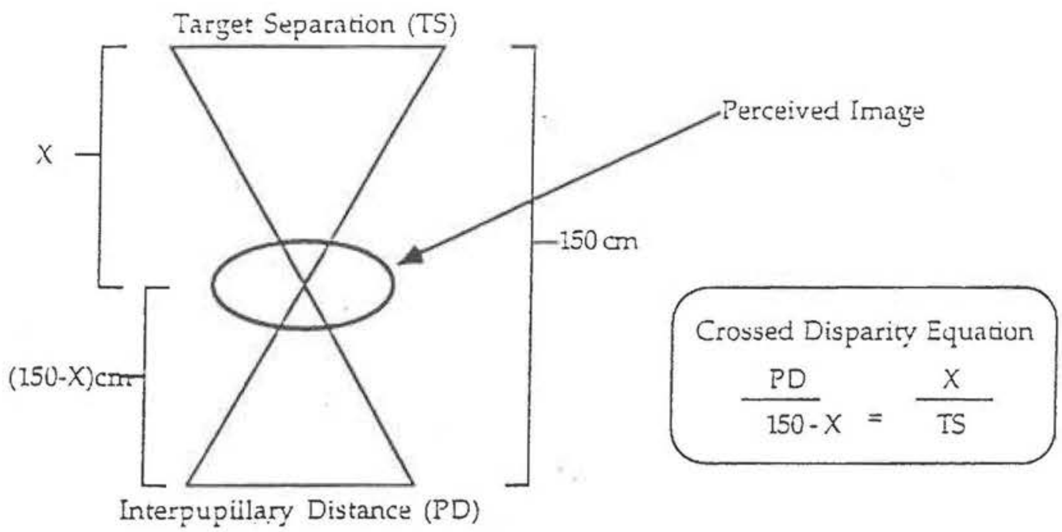


Fig 3: Apparatus Design

Trigonometric Method for Calculation of Theoretical Perceived Image Location

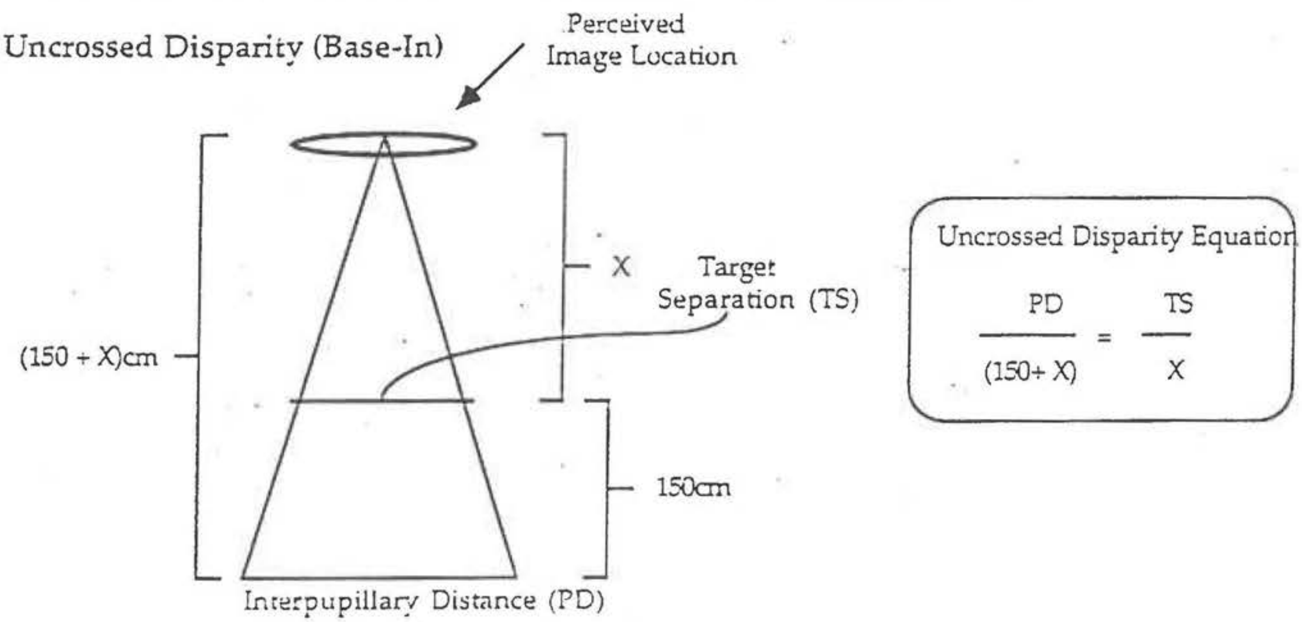
Crossed Disparity (Base-Out)



Crossed Disparity Equation

$$\frac{PD}{150 - X} = \frac{X}{TS}$$

Uncrossed Disparity (Base-In)



Uncrossed Disparity Equation

$$\frac{PD}{(150+X)} = \frac{TS}{X}$$

Fig 4 11

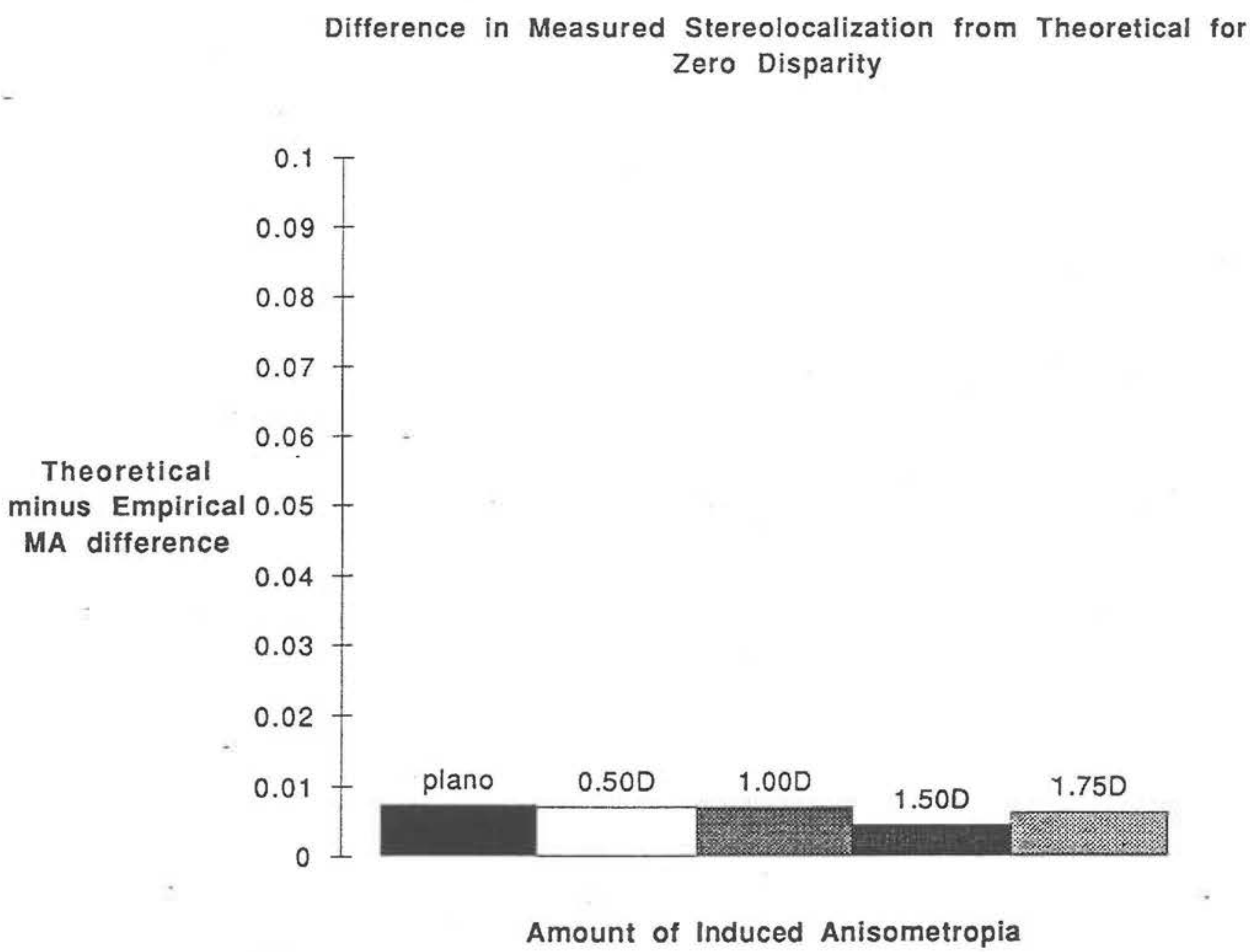

Difference in Measured Stereolocalization from Theoretical for Zero Disparity
Theoretical minus Empirical MA difference
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
plano
0.50D
1.00D
1.50D
1.75D
Amount of Induced Anisometropia

Figure 5

Difference in Measured Stereolocalization from Theoretical for Crossed Disparity

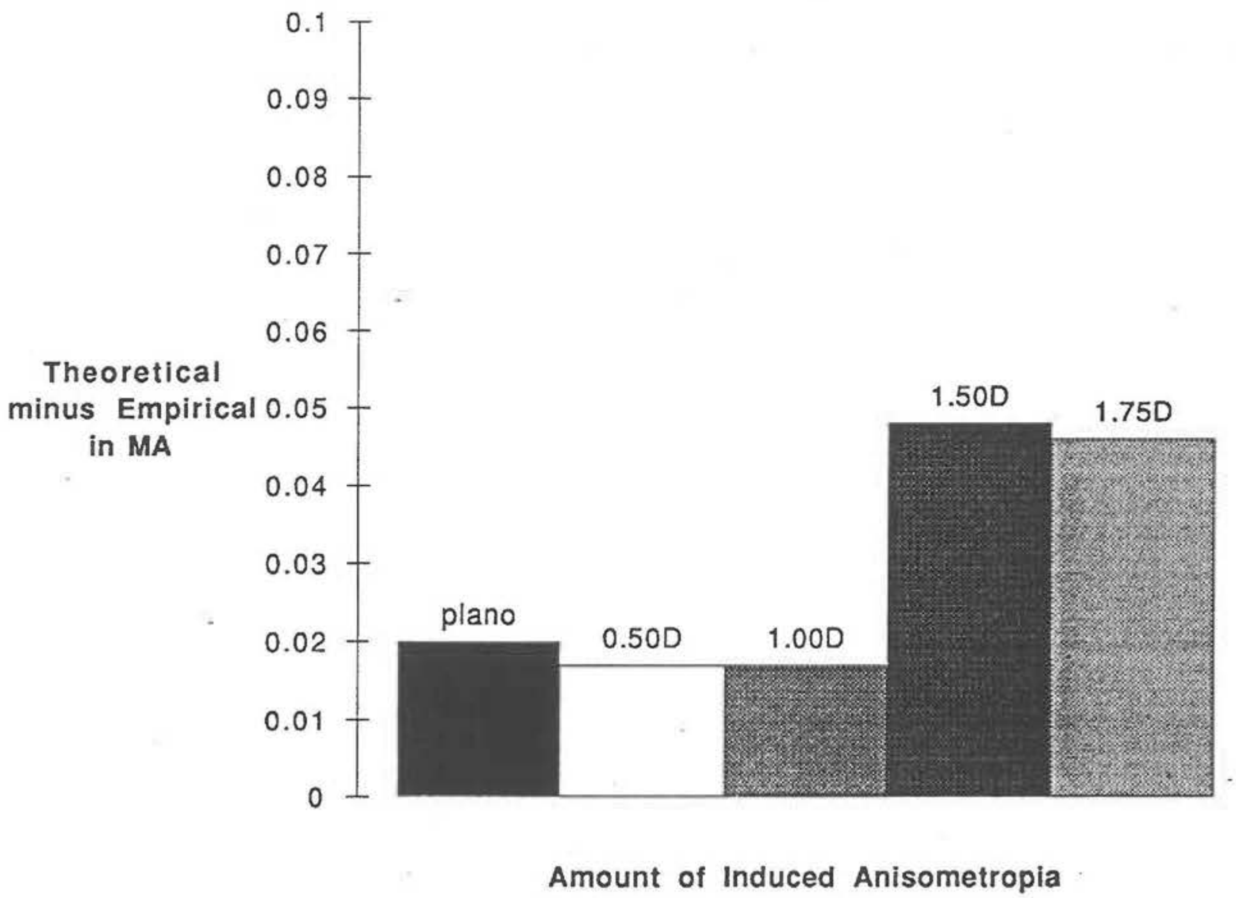


Figure 6

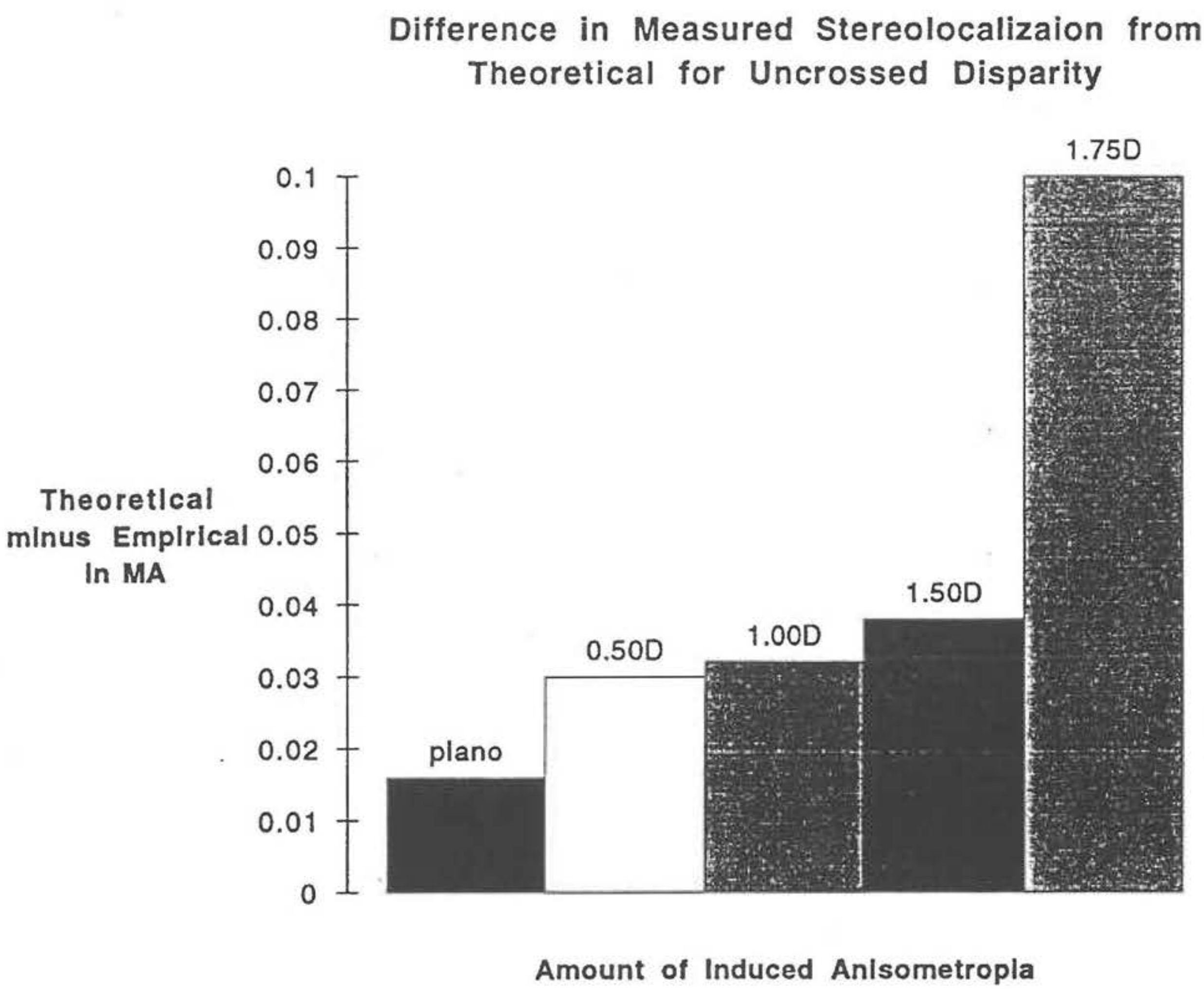

Difference in Measured Stereolocalizaion from
Theoretical for Uncrossed Disparity
Theoretical
minus Empirical
in MA
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
plano
0.50D
1.00D
1.50D
1.75D
Amount of Induced Anisometropia

Figure 7