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# Effects of yoked prism on spatial localization and stereolocalization

Daniel R. Hock
*Pacific University*

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### Abstract

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# Effects of Yoked Prism on Spatial Localization and Stereolocalization

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Daniel R Hock

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Advisor:
Bradley Coffey, OD., FAAO

Daniel R Hock

Daniel R Hock

Bradley Coffey, OD FAAO

Bradley Coffey 10.94

## About the Author

Dan will be practicing full scope, primary care optometry in Evergreen, Colorado.
Interests: family, vision, mountains, bagpipes

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## ABSTRACT

The effects induced by yoked prism on spatial localization and on stereolocalization were assessed using two different two-dimensional spatial localization tasks and a polarized three dimensional localization apparatus. Subjects were 34 young healthy adults who met entrance criteria related to normal visual function. The subjects wore 15 prism diopter horizontal and vertical yoked prisms, and measurements were recorded assessing the shift of visual space perception in horizontal (x), vertical (y), and the perpendicular to (x) and (y), the near to far (z) axis. The effect of yoked prism on stereolocalization was examined by comparing perceived stereoscopic float of a vectographic target while subjects wore base up, base down, or plano lenses. Spatial perceptual shifts using two different tasks were quantified in visual feedback-free conditions. Significant shifts were detected in all testing conditions. The degree of spatial shift is related to the task performed. Also, on effect of vertical yoked prism on stereolocalization was statistically verified. Base up yoked prism creates perceptual modifications which cause subjects to stereolocalize 3cm further away in space (at a testing distance of 1.5m) than a plano lens condition. Base down prism moves stereolocalization responses 3cm closer to individuals than a plano lens condition. Perception of stereolocalization is altered by 6cm comparing 15pd base up to 15pd base down, at a testing distance of 1.5m. These results provide evidence of alterations in visual space perception associated with wear of yoked prism.

**Key Words:** crossed and uncrossed disparity, depth perception, stereolocalization, spatial localization, yoked prism, perception

## INTORDUCTION

Yoked prisms are defined as a pair of prismatic spectacle lenses of equal power with bases oriented the same before each eye. We know when viewing the world through a prism that the apparent location of all objects is shifted toward the prism's apex. It has long been clinically understood that prism shifts visual space in the direction of the apex in the approximate linear relationship of 1 cm displacement at a distance of 1m= 1pd (prism diopter). At one meter a 15 pd prism will deviate images 15 cm in the direction of the apex, see Appendix 1. This amount of linear deviation is directly proportional to the distance between the prism and the viewed object (Prentice law). A person's adaptation to the prism-displaced image involves an ocular movement to align the retina with the new stimulus position. A corresponding proprioceptive change occurs in the extraocular muscles. Eye position is represented by neural commands to the extra-ocular muscles. These commands change the motor-sensory relationship of the past response. When a person adapts to the new response pattern presented by a yoked prism stimulus, behavioral changes occur.

In order to begin a discussion of some of the concepts surrounding yoked prism and spatial perception, one must first look at previous research that has documented lens-induced changes in spatial perception. The binocular system's relationship with perception will be addressed, as well as some history of yoked prism use in optometric vision training. This background information needs to be explored in order to relate perceptual shifts to explanations of why yoked prisms have such profound effects on an individual's behavior. Quantification of spatial localization and stereolocalization will bridge a scientific gap bringing us closer to understanding the perceptual modifications responsible for altered behavior.

It has been shown that changes in perceived distance occur due to manipulation of the binocular vergence system. Effects of fixation disparity and heterophoria on spatial localization have been documented [1-5]. A person undergoing a vergence system alteration is forced into new motor learning from new sensory inputs. "Spatially oriented behavior consists of sets of stimulus-response connections established through early learning. When vision is subsequently transformed, the old visual-motor relations lead to mislocalization."[6,7] Those of us who have worn "compensating prescription lenses" have likely experienced distorted vision the first time we put them on. The distortion may have been severe enough to cause difficulty in motor coordination, e.g., as in reaching for something that wasn't where we saw it or in being unsure of where we were stepping. However, we also recall that in a few days the distortions disappeared and coordination followed.

No study to date has quantified the perceptual response to the calculated prismatic displacement in visual space. There is, however substantial literature on visual adaptation to distortions involving spatial geometry.[8] The application of distorting goggles to the study of visual adaptation dates back to the 1920's and the work of Stratton. He used himself as his subject because he underwent extensive adaptative periods wearing prismatic goggles for weeks and months at a time. He found that he could eventually adapt fully to visual worlds that were inverted or reversed.[8] About the same time period (circa 1930) Erismann and Gibson began experiments independently. In one study an Erismann subject became so at home in his inverted world that he was able to drive a motorcycle through Innsbruck while wearing the distorting goggles. These early perceptual adaptation studies were extremely useful because they proved that visual perception can be altered and that human subjects can learn and adapt to new visual environments.

Considerable research on animal subjects and adaptation to altered visual worlds has also been conducted. Psychologists had experimented extensively with visual deprivation in the 40's and 50's, using behavioral methods to assess the effects.[9] Beginning in the 60's deprivation studies were being conducted by neurobiologists who were able to relate some of the behavioral studies to nervous system (visual pathway and visual cortex) physiology. The advent of the microelectrode allowed the pioneer neurobiologists a tool to begin relating function to neurophysiology. Hubel and Wiesel were able to produce tangible, or observable, physiological and morphological changes in the nervous system without actual physical intervention.[9] It has long been known that cells in the nervous system degenerate if a nerve is cut or crushed. What made Hubel and Wiesel's work so interesting was that the visual cortex cells examined were not physically altered. Retinal cells were denied light or compromised by altering the retinal loci by inducing strabismus. These cortical receptive fields were "soft wired" and extremely susceptible to experential modification. Essentially, these retinal cells altered the visual cortex cells, proving that the human visual cortex is plastic and nervous system modifications are possible.

Next, we will examine literature suggesting visual modifications exist simply by adaptation or habituation to yoked prism wear. While the definitive yoked prism adaptation theory is disputed, the phenomenon of yoked prism adaptation has been supported repeatedly.[10,11] The nature of yoked prism effects on spatial perception probably exist intertwined in some of the following explanations.

The muscle potentiation paradigm was created as a result of studies conducted by physiologists. It is essentially a recalibration in efferent muscle command systems due to proprioceptive and other afferent sensory alterations. Ebenholtz and others maintain that changes in perceived target location (depth perception) are a result of changes in the binocular vergence system. The change in perception is a result of continued reflexive innervation of the extraocular muscles in the direction of the previous stimulus.[2,5] Potentiation in convergence tasks creates reduced innervation to maintain convergence posture. Afferent information will now be "real space" altered to the degree that the residual muscle tension must be counterinnervated. 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. Continued viewing of distant targets would generate reflexive divergence, voluntary convergence, and lesser perceived distances.

A second theory to explain prism related changes in distance perception is the adaptation paradigm, in which subjects use prism and spherical powered lenses to alter vergence and accommodative systems.[12] Adaptation is created in response to discrepancy between monocular cues and the oculomotor cues to distance provided by convergence and accommodation. This 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 conflict occurred. This result is most often quantified by recording measurements taken before and after a variable has been visually modified with lenses and prism. A difference in pre and post trials suggests some form of adaptation to a visually modified condition. If, for example, an object is viewed through lenses and prisms creating optical distances closer than the actual distance, oculomotor cues begin to signal increased distance after recalibration, and distance perception shifts toward the true distance. This theory does not consider the possibility that the spectacles used to alter distance cues also may have had hysteresis effects on the oculomotor system, i.e. heterophoria, and fixation disparity changes, which could account for changes in distance perception after lens and prism removal.

Wists' motor theory attempts to integrate eye movements, space perception, depth perception, and retinal disparity. Wist states, "The motor theory postulates that during scanning movements, which involve changing fixation between farther and nearer components of the visual field, proprioceptive inflow or command signal outflow information is provided to higher centers in the brain about relative convergence which in turn provides information about the depth relations of objects in the visual field."[13] Furthermore, some versions of his theory postulate a role for the absolute convergence of the eyes in enabling the perception of egocentric distance, the distance of a perceived object from the observer. Perceived size changes, which are known to occur with changes in convergence, demonstrate a relationship between perceived size and distance.[13]

The validity of Wists' psychophysiological motor theory is demonstrated when vertical yoked prisms are placed before the eyes. The vector of vision is displaced in the direction of the apex of the prism. The changes in visual motor integration will be created by the degree of the recalibration during prism wear and compensation.[14] Our brain's plasticity must then allow for recalibration of the input systems of proprioception, vestibulocochlear afference, muscle postures, and joint, ligament and tendon postures. If visual space is somehow altered with yoked prism and other sensory afference is negated, individuals have no contradicting information and will simply be experiencing a pure visual perceptual shift. When tactile and/or egocentric cues are presented as spatial feedback most individuals perceive space as altered but generally quickly adapt their visual world to correspond more closely with other sensory modality information. This is analogous to individual efferent system recoordination and hierarchical input system restructuring. All of this takes place within our brain, involving incredibly complex neurological linking and plasticity.

Held and Hein have extensively researched sensory-motor plasticity and the influence of feedback on sensory-motor and motor-sensory interaction and rearrangement. Held suggests the underlying principle to involve reafference.[15] Reafference is a motor-sensory feedback system which only occurs when there is a self generated movement. Reafference requires motor action to reaffirm motorically the natural quality of the sensory information. They found that cats that were guided through a maze without motor-sensory input could not learn how to get out of the maze and find a treat. Cats that were allowed motor-sensory input quickly figured out the maze and could quickly locate the way to the end of the maze and the treat.[15] These experiments have demonstrated a fundamental role of the motor-sensory feedback loop. Motor-sensory learning occurs resulting in a gradual shift from the older mode of space interpretation to the new one. Held's work also makes two additional important points.. That the spatial control system exists in the central nervous system, and that adaptation to perceptual rearrangement affects motor coordination and development. Kaplan feels vertical yoked prisms are an associative device that produce reafference by changing input to create changed motor responses He feels that the optical properties of prisms create spatial rearrangements which, in turn, effect temporal changes for the wearer.[16]

Traditionally, there has been a distinction between sensation and perception. If someone is exposed to red light, the 570 NM cones begin the chemical/electrical transition leading to a cascade of action potentials and the viewer responds that s/he saw red light; this was considered to be a sensation. If this individual responded that what s/he observed was an exciting warm color, or visualization of a stop sign took place, these feelings and interpretations were considered to be perceptions. The geometry of binocular vision involves quite different problems than that of color vision, and motion, contrast, and spatial perception.[17] The construction of space, when consistent and reliable, leads to a knowledge of space from which an individual can more meaningfully interact. When we alter the system and learn a new way of functioning, we do not believe we are forcing the system to function artificially or abnormally. We assume, rather, that a single mechanism (adaptation) is at work at all times. The mechanism that removes or minimizes an artificially created visual distortion is the same one that brings about normal functioning of the sensory system under habitual visual conditions.[8] The building of a knowledge of space requires learning, development and perception.

The perceptual systems do not have the capacity to evaluate every piece of afferent information simultaneously. The perceptual processes, such as visual form discrimination, visual closure, figure ground perception, visual-motor integration, spatial orientation, and spatial visualization all enable an individual to handle this great amount of information efficiently.[18] Since perception is in part a discrimination process, it involves a process of selection from the available input of sensory and motor stimulation. Without this discrimination process information overload would result.

Perception is not a cognitive activity, it is both clouded and enhanced by past experience and existent attitude. Perception influences such basic skills as gross motor and fine motor development, eye hand coordination, laterality awareness and directionality, form perception, and visual motor development.[18] Gross motor development is intimately associated with Piaget's body schema concept in which an individual's body image provides the basic reference point for all spatial relationships among objects occupying outerself space. These perceptual-motor modifications are consistent with Skeffington's hypothesis, which is the basic premise of the Optometric Extension Program approach to vision care. Skeffington believed the individual's visual perceptual information processing abilities can be functionally modified by specific environmental stimulus interactions. That is, the functional interactions of an individual with the environment will shape, modify, and otherwise control the visual nervous system structure. Skeffington believes that the degree to which the organism is placed under stress will determine the direction and efficiency of these structural modifications. Adaptive perception should be considered a basic survival mechanism.

All information is encoded in neurological electrical potentials and from this a three dimensional world is constructed.[19] This space world is dependent upon an individual's personal perception, and creates a personal reality that is comprised of past experience and information presently being processed.[17] Consider the example of tossing a bean bag with disruptive yoked prism. Space is altered and the motor program responsible for tossing the bean bag responds with misguided visual direction. The adaptation is only created when the reality of the misguided bean bag lands far from its original real space destination. This error is a direct result then of past experience and the altered perception.

Two dominant patterns of visual space organization, "central" or "peripheral," have been described.[20] Classification as central or peripheral is an attempt to label how an individual views his space world, processes information, and responds to the entire environment. Forrest and Birnbaum have found that esophoric individuals demonstrate a visual information processing style that is centrally organized. Exophores are shown to be influenced by peripheral processing.[21,22,23] Utilizing the Children's Embedded Figures Test (CEFT)[24] a significant difference was found between male esotropes and exotropes in their processing styles. Birnbaum concluded that direction of oculomotor deviation and cognitive/perceptual style may be related to hemispheric organization. Yoked prism is used therapeutically to influence central-peripheral organization.[25] It is used to control the rearrangement of photoreception and thereby stimulate movement awareness. Low magnitude prisms (under 5pd) are "directive" in nature and stimulate "visual capture" which leads to "visual consolidation" and reorganization of visual space.[16] Kaplan uses directive yoked prisms' spatial expansion and compression characteristics to affect patients' eso or exo behaviors.[26]

Large magnitude yoked prisms (15 pd and over) are "disruptive" in nature and stimulate reorganization of the visual-motor complex.[27] Perceptual reorganization must take place in order to adapt to altered space. Base up yoked prism is viewed as spatially compressive, with illusionary spatial cues shifted downward, closer, and smaller. It may facilitate awareness of figure and central visual attention in global and/or distractible individuals.[16,28] Kaplan suggests using base up for convergence insufficiency. Base down yoked prism is spatially expansive, with illusionary spatial cues shifted upward, farther, and larger. Kaplan suggests using base down for convergence excess.[25]

Yoked prisms' effects on spatial relationships have made them a valuable tool in the training/therapy practices of behavioral optometrists. The Optometric Extension Program ran series by Horner in 1972-1973, Kaplan in 1978-1979, and Kraskin in 1981-1983, that all advocated yoked prism as having both diagnostic and therapuetic uses. According to these reports patients using vertical yoked prism have reported:

1) decreased asthenopia
2) increased reading comprehension

3) decreased motion sickness

4) improved peripheral awareness

5) increased sports performance

Kaplan reported changes in eye coordination, acuity, refractive state, the AC/A ratio, and positive relative accommodation associated with yoked prism wear. He also found that yoked prism creates a SILO effect, an acronym for "smaller in larger out".[29] The SILO responder uses vergence as a cue for his perception of distance. This person perceives an object to be moving closer when s/he is converging because s/he "knows" from previous experience that when s/he converges it means s/he is looking at an object moving closer.[30] This interpretation reveals input system structure primarily reliant upon the vergence system. It is a reflection of an individual's perceptual style and attention to visual stimuli.[30] SOLI responders rely predominantly on retinal angular subtense and perceive smaller objects as being further away in space, a perceptual outcome that is consistent with real world experience.

Kraskin believes vision disorders are the result of postural skews and advocates the use of yoked prism to induce postural changes.[31] He relates refractive state to the tonicity of the lower back musculature. A myopic individual would be considered hypertonic and the hyperope would be hypotonic in this paradigm. Kraskin lists possible beneficiaries of vertical yoked prism therapy as individuals with the tonic compensations leading to myopia and hyperopia.[25] Horizontal yoked prism is used for patients with asymmetric conditions of anisometropia, strabismus, amblyopia, unequal phorias, and postural distortions. Kraskin prescribes disruptive prism in the direction that impairs stereopsis. This exaggerates postural stress and provides a stimulus for the individual to rebound by organizing a postural response to counter the induced stress. Kraskin suggests the real value of yoked prism is in the alterations of orientation created by influencing the twenty percent of retinal fibers leading to the lower brain centers involved in posture, movement, and stability.[31]

The oculomotor system has been shown experimentally to contribute to spatial localization.[25,32] The version system helps to locate objects in left-right and up-down relation to the individual, axes x and y. The vergence system helps to locate objects that are near or far on the z axis. It is obvious that horizontal yoked prism affects the version system. It is not known what effect yoked prism wear has on the vergence system. The vergence system plays a substantial role in the calibration of depth into perceived distance and the perception of three dimensional space.[32] Phoric posture differences existing in different vertical positions of ocular gaze are described as *A* or *V* patterns. An *A* pattern is defined as an increase in exophoria or decrease in esophoria as the eyes shift from superior gaze, to primary gaze, to inferior gaze. A *V* pattern has a greater amount of exophoria (or less esophoria) when the eyes are in superior gaze, relative to primary gaze. The primary gaze posture would be more exophoric (or less esophoric) than inferior gaze posture. Regardless of *A* or *V* patterns, phoric posture or even fixation disparity, it is hypothesized that localization is altered as spatial perception is modified.

Concave lenses and base out prism affect spatial judgment by increasing the perceived distance of stereoscopic float from the observer for SOLI responders.[33] In a SILO responder these lenses move the perceived target closer to the observer, farther from the true target location. High amounts of artificial anisometropia decrease the amount of float perceived by subjects under both crossed and uncrossed disparity conditions.[34]

Yoked prisms cause a noticeable subjective shift in the spatial localization of visual information.[35] This seems obvious to anyone who has worn yoked prism, although this effect has never been quantified. Both clinical experience and research suggest a perceptual spatial shift. It is not known and has been contrastingly hypothesized what alterations, if any, exist on stereolocalization induced by yoked prism. Stereolocalization refers to the ability to make a z-axis judgment of where the target appears to be when fusion occurs, and is related to the concept of physiological diplopia.[30] This measurement can be accurately achieved and statistically verified using a variable vectographic apparatus developed by Fredrickson and Gorham.[36]

In a hyperstereolocalization response the subject perceives the float between the subject and the mathematically predicted location of float, a hypostereolocalization response is perceived beyond the mathematical location of float. (See Appendix 2 for explanation of perceived float of vectographic targets.) The convention used here is analogous to that used to describe hyper and hypotonic accommodative posture, and does not suggest hyper as being above or greater than and hypo as below or less than. It is viewed that any localization response other than the mathematical point of localization is erroneous. The same amount of hyper and hypo deviation is then considered equally aberrant.

One can hypothesize several potential outcomes on stereolocalization due to base up and base down vertical yoked prism (BU and BD VYP):

1) Third dimensional space is altered- a clinical hypothesis based on spatial expansion and compression characteristics of yoked prism
   a) BD VYP causing hypostereolocalization
   b) BU VYP causing hyperstereolocalization
2) The perceptual shift theory- afferent information mismatch which is based on altered perceptual locations in space
   a) BU VYP creates hypostereolocalization
   b) BD VYP creates hyperstereolocalization
4) Yoked prism does not create a change in stereolocalization
5) Yoked prism alters space differently dependent upon
   a) fixation disparity
   b) heterophoria
   c) A or V vergence patterns
   d) SILO or SOLI responder

Further experimentation regarding yoked prism effects on spatial localization and stereolocalization needed to be conducted. This study was designed to quantify the effects of both horizontal and vertical yoked prism on horizontal (x) and vertical (y) planes of space. Experimental conditions were controlled so that subjects were unable to use visual feedback as a means for correcting mislocated outcomes to a task. The effects of vertically yoked prism on the z axis will be examined by stereolocalization measurements. It is hypothesized that there not only exists a (y) axis shift with vertically yoked prism but that a (z) axis shift is created as well. This z-axis shift will effectively be measuring a perceptual alteration. Are spatial localization and stereolocalization influenced by vertical yoked prism? And if so, is it a clinically useful shift that can be implemented into a therapy or lens prescription regimen altering space in a functionally useful direction?

# METHODS

## Subjects

Thirty four (15 female and 19 male) first year optometry students in their first two weeks of class with ages ranging from 21 to 42 years old were subjects. Subjects were naive as to effects of yoked prism on vision. Initial evaluations were done on each to exclude those with binocular dysfunction as specified below.

### INSTRUMENTATION:

### X and Y-axis spatial localization

The purpose of this part of the research was to quantify x and y-axis subjective spatial localization when yoked prism is used as a visual modifier. A feedback-free task required subjects to throw black darts at a target located on a black board in a dimly illuminated room. Subjects wore horizontal and vertical yoked prism, which altered visual perceptual space localization.

A two cm diameter yellow circle was centrally positioned on a black sheet of fabric which was draped over a cork board mounted vertically on a wall. Subjects were instructed to throw black darts at the yellow circle target. Subjects threw five darts in each of five trials of different lens conditions from a distance of 2.5m. The room illuminance was set to 10.8 lux (lumens/meter$^{2}$). Experimental conditions were controlled so that subjects were unable to see the final position of each dart after it was thrown. Upon release of the dart feedback was minimized to auditory and egocentric cues. The dart in flight, and once it stuck in the black board, was invisible to the subject. (see Appendix 3)

**Z-axis spatial localization**

A similarly designed task required subjects to toss black bean bags while wearing vertical yoked prism in order to quantify subjective z-axis, distance perception changes. A two cm in diameter yellow circle was centrally positioned on a black sheet of fabric which was draped over a board and laid flat on the floor. Subjects tossed bean bags made of the same fabric as that which covered the board. Subjects stood behind a line on the floor positioned 2.5 m from the center of the yellow target. Again, visual feedback was eliminated by the black bean bags not being able to be seen on the black board where the target was located. (see Appendix 4)

**Quoits variable vectographic apparatus**

The scope of this part of the investigation was limited to the effects of vertical yoked prism on stereolocalization. The Quoits target subtends a visual angle less than 5 degrees and is considered a central target. The target size was approximately the size of a softball viewed at a distance of one and one-half meters. Norms for stereolocalization, both for crossed and uncrossed disparities, were developed by Fredrickson and Gorham[36] on the Quoits Variable Vectographic apparatus. They found subjects localized quite accurately for both disparity types, when compared to the mathematically calculated expecteds. A difference of 1% or less exists between theoretically determined response and the real, measured response.[36]

The Quoits ring apparatus was created to quantify subjects stereolocalization and to compare these results to what is mathematically calculated by trigonometry and disparity measurements. A 9 mm uncrossed disparity was used in this study based on Fredrickson and Gorham finding that disparity to be the most accurately localized. They found a 0.001 MA difference between theoretically and empirically calculated stereolocalization measurements.

Subjects' stereolocalization was measured in real space using a Stereo Optical Quoits vectographic target suspended by monofilament line in a transparent holder. Subjects wore polarized lenses oriented in a direction which created uncrossed disparity. Two opposing polarized targets which are round and 9.3cm in diameter make up the Quoits target. The 9mm uncrossed disparity corresponds to a fusional demand of 1.2 prism diopters base in. The subject was seated and positioned with in a chin rest clamped to the end of a table. The distance between the Quoits vectogram and the chin rest was 1.5m.

Peripheral cues were minimized by using a plain white cloth curtain which completely surrounded the table and apparatus. Additionally, a black sheet was draped on the 2.46m of the track inside the apparatus. The sheet had a thin linear cut in it to allow a vertical black pointer to be moved closer to, or further from the subject. The pointer was attached to a cart which is remote controlled by an experimenter to position the cart where the subject perceives the float. The cart had a horizontal pin marker which points directly to a two meter stick where measurements were taken by another experimenter. The subject was instructed to verbally indicate when the black pointer was directly aligned beneath the perceived floating target. The subjects were encouraged to take their time and as many modifications as needed were given until they were certain of alignment. Appendix 5 schematically represents the apparatus.

## Procedures

Each subject was treated in a similar manner as described in the following protocol: (see Appendix 6 for entire protocol)

1) Each subject read and signed a informed consent form. (see Appendix 7)
2) Entrance data were taken and recorded.

The following entrance criteria were used:

a) Habitual monocular and binocular visual acuity of at least 20/40 at 6m measured on the BVAT[a] (a computer-controlled acuity and binocular vision testing device)
b) Stereo acuity of at least 60 sec of arc as measured with the BVAT
c) Fixation disparity less than 3 min of arc measured with the BVAT
d) No history of, or current indications of strabismus as measured using the unilateral cover test at 6 m and 40 cm. No A or V pattern greater than 6 pd tested at 1.5m

3) Other measurements taken were:

a) Subjective impression of SILO-SOLI
b) Interpupillary distance with fixation at 1-5m

c) 6m Maddox rod phoria

The SILO-SOLI assessment was accomplished using the Topper vectogram (Stereo Optical Corp[b]). Subjects were asked first to describe any size change they noticed in Topper as crossed disparity was increased. If they responded "smaller" ortho disparity was created. Subjects were next asked to describe any apparent change in Topper's location as crossed disparity was increased. Did Topper appear to be moving further away, closer to, or was no change in localization observed? Subjects who noticed Topper become both smaller and closer were categorized as SILO responders. SOLI responders subjectively noticed Topper become smaller and further away in localization.

Commercially available instrumentation was used for this research. The lenses and prisms utilized were 66mm diameter round, clear, plastic lenses with front base curves of +6.75 diopters. Each had four small pieces of velcro glued to the back surface. The corresponding velcro match was glued to goggles available from GTVT[c]. The design of this goggle lens system is attributed to Dr. Frank E. Puckett. The goggles were worn over the subject's existing prescription eye glasses or contact lenses. One pair of plano lenses was utilized as a control condition. One pair of 15 prism diopter lenses was utilized in yoked prism base orientations as specified for each individual task, described next.

4) Subjects who qualified for the study performed the x and y-axis dart throwing task preceded by the following instruction set.

> "You will be throwing darts at a small dot which is located on a black board. You should attempt to throw each dart directly at the dot. No compensation should be made for any feedback you may feel from throwing the previous darts. That is to say, throw each dart as if it was your first and try and pay no attention to any feelings that you may have about where your previous dart headed after you threw it."
>
> "You will be throwing five darts under five different lens conditions. After five darts have been thrown, I will ask you to turn around while measurements are being recorded, I will also be making a lens change before you throw your next five darts."

After throwing a trial of five darts subjects were asked to turn away from the target while measurements were recorded and new lenses were placed on the subject before the next trial of five darts were thrown. Subjects threw darts under 15pd of BU VYP, BD VYP, BR HYP, BL HYP, and PLANO lens conditions in counterbalanced order.

Data were gathered by measuring the distance from the center of the target to the position of the dart when it was stuck in the board. Cartesian coordinates were used to describe each dart's position. Darts positioned in the superior right quadrant where recorded as +x, +y. Darts positioned in the superior left quadrant were recorded as -x, +y. Darts positioned in the inferior left quadrant were recorded as -x, -y. And, darts positioned on the inferior right quadrant were recorded as +x, -y (see Appendix 8). The center of the target was designated as the zero x and y-axis value.

With the plano lens condition measurements of both the x and y-axis positions of the darts were recorded. Vertical yoked prism conditions measurements were recorded on the y-axis only and horizontal yoked prism conditions were recorded on the x-axis only. The plano condition was used to establish each subject's habitual position in order to quantify individual shifts from habitual positions. Individual data were calculated as changes from habitual and these individual changes were computed and compared across the entire subject sample. A net change could be statistically analyzed and a quantification of spatial localization could then be established.

5) Subjects who qualified for the study performed the z-axis bean bag task preceded by the following instruction set.

> "You will be tossing bean bags at a target located on a black board. You should attempt to place the bean bag right on top of the target with each toss. No compensation should be made for any feedback you may feel from tossing the previous bag. Attempt to toss each bag as if it was your first toss."
> "You will be tossing five bean bags under three different lens conditions. After you have tossed five bean bags I will ask you to turn around while measurements are being recorded, and I will make a lens change before you toss your next five bags."

After tossing a trial of five bean bags subjects were asked to turn away from the target while measurements were being recorded by two experimenters, during which time another experimenter changed the lens condition. Subjects tossed bean bags under conditions of 15pd BU VYP, 15pd BD VYP and plano lenses.

Z-axis localization measurements were recorded as the near-far linear error from the target line to the center of the bean bag. Measurements were recorded on the z-axis only as we were only concerned with effects on this aspect of space; no vector relationship was recorded. The center of the target was considered the zero z-axis value. Bean bags positioned beyond, or further from the target than the subject were given positive values. Bean bags positioned closer to the subject from the zero z-axis value were designated as negative values. (see Appendix 9)

6) Quoits variable vectographic apparatus testing was preceded with the following instruction set:

> "Inside this apparatus is a ring that will appear to be floating in space. The ring may appear to be moving or fluctuating closer to or further from you. Take a few moments to allow the ring to stabilize in position. You will notice that below this ring is a small vertical black pointer which can be moved by me along a track. I would like for you to verbally indicate in which direction I must move the pointer in order for it to be positioned directly below the floating ring. As many pointer modifications as needed will be allowed."
>
> "We will begin by placing these goggles upon your face. You need to comfortably position yourself on this stool and place your chin on this chin rest."
>
> "We will be taking three measurements under three different lens conditions. Between measurements I will alternately move the pointer way in front or way behind the ring's floating position. After the third measurement I will ask you to remove your head from the apparatus and I will adjust the lenses before our next trial."

Measurements were recorded when the subject was certain about pointer and ring alignment. The Quoits target was presented in uncrossed disparity yielding a predicted mathematical location of float approximately equal to 177cm from the subject's chin, positioned at 1.5m from the vectogram.

Formula for calculating uncrossed disparity

$$\frac{\text{mean interpupillary distance}}{(150cm+X)} = \frac{\text{Target separation}}{X}$$

target separation=9mm
mean interpupillary distance=58.735mm
X= calculated distance of stereoscopic float X=27.14cm
chin position to vectogram=150cm

150cm+27.14cm=177.14cm

## Experimental Design

Counterbalanced orders of lens presentation were selected randomly for each subject. Alteration sequences were as follows for the x and y-axis spatial localization dart throwing task:

| | | | | | |
|---|---|---|---|---|---|
| 1 | $PL_{1-5}$ | $BD_{1-5}$ | $BR_{1-5}$ | $BU_{1-5}$ | $BL_{1-5}$ |
| 2 | PL | BL | BU | BR | BD |
| 3 | BU | BL | PL | BR | BD |
| 4 | BD | BR | PL | BL | BU |
| 5 | BD | BL | BR | BU | PL |
| 6 | BR | BU | BD | BL | PL |
| 7 | BU | BR | BD | PL | BL |
| 8 | BD | PL | BL | BR | BU |

Lens presentation sequences were as follows for both the z-axis spatial localization bean bag toss task and for the Quoits variable vectographic apparatus.

| | | | |
|---|---|---|---|
| 1 | $PL_{1-5}$ | $BU_{1-5}$ | $BD_{1-5}$ |
| 2 | PL | BD | BU |
| 3 | BU | PL | BD |
| 4 | BD | PL | BU |
| 5 | BU | BD | PL |
| 6 | BD | BU | PL |

## RESULTS:

### X and Y-axis spatial localization task- (as measured by a dart task)

Changes in the tossed darts' endpoint locations associated with yoked prism wear were determined by calculating the difference in mean location in the plano condition and the mean location in each yoked prism condition. These differences by prism condition were analyzed using repeated measures ANOVA. Significant differences (F=183, df=33, p=0.0001) were present by condition, and were in the directions predicted by the optical displacement properties of the yoked prisms. These data are shown in table 1.

Positive numbers indicate bean bag localization further away on the z axis, negative numbers indicate bean bag localization as being closer to the subject (see Appendix 8).

**Table 1:**

**X and Y-axis Localization Values**

**Dart Throwing Task**

| | mean (cm) | std. dev. | std. error |
|---|---|---|---|
| Dt BD mean adjusted | 18.6 | 11.533 | 1.978 |
| Dt BU mean adjusted | -17.859 | 8.272 | 1.419 |
| Dt BL mean adjusted | 22.559 | 10.371 | 1.779 |
| Dt BR mean adjusted | -18.126 | 11.084 | 1.901 |

### Z-axis spatial localization task- (as measured with a bean bag task)

Changes in the tossed bean bags' endpoint locations associated with yoked prism wear were determined by calculating the difference in mean location in the plano condition and the mean location in each yoked prism condition. These differences by prism condition were analyzed using repeated measures ANOVA. Significant differences (F=293.3, df=33, p=0.0001) were present by condition, and were in directions predicted by the optical displacement properties of the yoked prisms. These data are shown in table 2.

## Table 2:

**Z-axis Localization Values**
**Bean Bag Toss Task**

| | mean cm | std. dev. | std. error |
|---|---|---|---|
| BBg Pl condition | -1.53 | 10.563 | 1.811 |
| BBg BD condition | 31.553 | 17.484 | 2.999 |
| BBg BU condition | -35.109 | 10.252 | 1.758 |
| | | | |
| BBg BD mnadj | 33.088 | 15.749 | 2.701 |
| BBG BU mnadj | -33.574 | 13.88 | 2.38 |

## Stereolocalization results as measured with the Quoits apparatus-

Changes in stereolocalization associated with yoked prism wear were determined by calculating the difference in mean location in the plano condition and the mean location in each yoked prism condition. These differences (F=136.5, df=33, p-value=0.0001) by prism condition were determined using repeated measures ANOVA. These data are in Table 3. Table 4 compares the mathmatical calculations (theoretical) and the results (empirical).

## Table 3:

**Quoits Apparatus Stereolocalization Results**

| | mean dist from | std. dev. | std. error |
|---|---|---|---|
| | subject in cm | | |
| Q Pl mean | 172.8 | 3.524 | 0.604 |
| Q BU mean | 175.9 | 2.982 | 0.511 |
| Q BD mean | 169.6 | 3.881 | 0.511 |

## Table 4:

**9mm uncrossed disparity table**

**conditions 15pd Base-up, 15pd Base-down, and Plano**

| | Theoretical distance in cm from subject | Empirical distance in cm from subject | Theoretical distance in Meter Angles | Empirical distance in Meter Angles |
|---|---|---|---|---|
| PL | 177.14 | 172.835 | 0.0056 | 0.0057 |
| BU | 177.14 | 175.9 | 0.0056 | 0.0056 |
| BD | 177.14 | 169.55 | 0.0056 | 0.0058 |
| | | | assume 60mm pd | assume 58.735mm pd |

*see Appendix 10 for significant differences by condition using post-hoc procedures

The only significant differences between our other potential variables was that SOLI responders have a significantly larger effect than do their SILO responding counterparts (see Appendix 10). There appears to be no significant effect of *A* or *V* pattern, gender, fixation disparity, heterophoria, or stereoacuity on the yoked prism measures in this study.

## DISCUSSION

**X and Y-axis spatial localization task-** (as measured with a dart task)

On average, of the four yoked prism trials, mean adjusted subjective space shift was found to equal 19.3cm, for the dart task done at 2.5m with 15pd yoked prism. Adjusted mean indicates that the mean subjective displacement of the four yoked prism trials have been factored with the plano condition mean. The results appear fairly symmetrical comparing BR, BL, BU and BD. The optical computation of target displacement for 15pd yoked prism at a distance of 2.5m would be 37.5cm. Under these testing conditions, subjective impression of space change is approximately half of what would be predicted strictly by the optics. It would be predicted that the further a subject is from a target the greater the disparity between subjective measurements and calculated optical displacement. The afferent muscular response would not represent a linear relationship with a prism induced visual space shift and target distance. Egocentric cues would mitigate against a subject's full response to prism-induced visual displacement. Subjects are aware that what is directly in front of them does not change when prisms are used to create visual displacement. The further a subject stands from a target, the greater the optical displacement and the more likely is the subject to partially respond egocentrically to this visual shift. It is not surprising that subject responses are not equivalent to optical displacement values. It is predicted that the relationship between subjective impression and calculated optical displacement will become more similar as target distances decrease, and less similar as distances increase.

**Z-axis spatial localization task-** (as measured with a bean bag task)

The average of the yoked prism trials mean adjusted scores for vertical yoked prisms effects on the bean bag toss task equaled 33.3cm. The results of this task are extremely symmetrical comparing the effect of base-down to base-up. The effect of the bean bag toss is much more robust than the dart localization task. Again, displacement of 37.50cm would be optically calculated, for 15pd yoked prism at a distance of 2.5m. It appears the afferent musculature responsible for tossing bean bags responds more to visual information than does the musculature responsible for throwing darts. It appeared that subjects were more accurate when tossing bean bags (less variability) and are more confident in hitting the target. This increased confidence appears to make subjects more reliant on visual cues, and less reliant upon egocentric cues. Subjects appear to toss their bean bags more to where they see the target and less to where they "feel" that the target should be.

**Stereolocalization as measured with the Quoits apparatus-**

There is a significant difference in stereolocalization responses when comparing BD VYP, to BU VYP, to a plano condition. BD VYP causes subjects to stereolocalize 3cm closer in space than when a subject is wearing plano lenses. BU VYP causes subjects to stereolocalize 3cm further in space than when a subject is wearing plano lenses. At the testing distance of 1.5m, there exists a 6cm difference comparing BU VYP to BD VYP stereolocalization values. The effects of yoked prism on stereolocalization have been questioned clinically, but no scientific data previously existed to clarify the issue. The results of this study seem consistent with several properties of yoked prism that have been previously examined.

It is prudent at this time to discuss some of the optical properties of yoked prism in order to rule out effects of target image size. No difference in refractive power should exist when comparing the trial conditions as discussed below.

Yoked prisms used clinically are typically plano prisms of standard base curve. The visitor spec goggles and lenses used in this experiment had a back surface base curve of -6.75 diopters and a front surface curve of +6.75 diopters. The back surface power through the center of this prism is plano, however, back surface power when looking toward the base or apex is not plano.[37] Induced back surface power through visitor spec lenses (front surface beveled plano prism) is +0.64+0.89x180 when viewed 40 degrees toward the base and -0.62-0.92x180 when viewed 40 degrees toward the apex.[37] Viewing toward the base yields plus power and plus cylinder and viewing toward the apex yields minus power and cylinder. The effects of viewing toward the apex at vertex distance of 17mm (which is the approximate value with the visitor spec goggles) is a small amount of minus power and cylinder. At the 1.5m distance of the Quoits target the angular subtense formed by visual displacement is 8.53 degrees for 15pd of yoked prism. This angle will create an irrelevant amount of minus power and cylinder because both the base-up and base down conditions have 8.53 degrees as a constant. No difference in refractive power should exist when comparing these two trial conditions. A different refractive power would only be created comparing the vertical yoked prism conditions to the plano lens condition. This small amount of concave refraction is believed to be negligible in this case due to the comparatively small angular change (8.53 degrees compared to the 40 degrees used in Streff's computations).

Base down yoked prism causes the eyes to move upward, and we associate that with greater target distances and smaller retinal image size. However, retinal image size of the Quoits target does not change. Therefore subjects conclude that the target must have moved closer and consequently localize it closer. A similar corollary can be worked through with base up yoked prism, the result is that subjects localize further in space. These examples assume that the subject is from a culture where larger angular objects are perceived as closer, and smaller angular objects are perceived as more distant. A story has been told of an Amazon jungle tribesman who first viewed some distant cattle on an open expanse of rangeland. The tribesman believed the distant cattle to be some kind of strange insects. He had never been in such a vast environment before. His world was tightly enclosed due to the dense vegetation of his native jungle. It was inconceivable to him that these strange insects were actually enormous animals weighing well over 1,000 pounds. In his culture angular subtense plays little role in size judgment; he relays on quite different cues.

This explanation is supported by comparing SILO responders results to SOLI responders results (see Appendix 10). It was found that SOLI responders had larger effects on stereolocalization (they localized further away from the plano condition, both hyper BD VYP and hypostereolocalization BU VYP) than did their SILO responder counterparts. SOLI responders rely on image size to ascertain localization while SILO responders localize predominately by information incoming from their vergence system. There should be little change in vergence posture because all subjects had A or V patterns less than 6pd. The only categorical variable that differed between subject groups was that the SOLI responders had a larger measured stereolocalization effect compared to SILO responders.

Some portion of the stereolocalization effect seen in this study may be explained by the perceptual change induced by the yoked prisms. Base-down yoked prism is associated with moving center of balance backwards, in the direction of the heels.[38] This shift creates a perceptual modification of being further from the target. This perceptual shift would cause subjects to stereolocalize a target closer (hyper) to maintain a constant perceptual distance between the target and the observer. Base-up yoked prism causes a forward rotation in standing center of balance.[38] This forward shift might cause subjects to localize further away (hypo) because they perceive their egocentric space as shifted forward. It may well be that the target appears to be in the same position of space regardless of base-down, base-up, and plano conditions. The difference in localization is due to a perceptual shift, a modification produced by altering visual space and creating a mismatch with other afferent information. A portion of this perceptual shift is perhaps what is being quantified by the stereolocalization measurements.

The chins of the subjects were stabilized in the position of the chin rest when measurements were being taken, yet the extraocular muscles were required to adjust for the displaced image. The adjustment the extraocular muscles made could transfer to a shifting of perceptual planes caused by a mismatch between visual and proprioceptive-kinesthetic afferent information systems. This mismatch can be further examined and quantified by some simple trigonometry and a perceptual model can be constructed.

Similar triangles can be used to examine the perceptual mismatch that the extraocular muscles would be responsible for inducing. Ten subjects had the vertical distance from bottom of chin to center of pupil measured and then averaged. A mean value of 12.5cm was obtained. A perceptual adjustment strictly from the extraocular muscles can be approximated to 1.88cm (see Appendix 11). This justification is approximately two thirds of the 3cm effect we found using the Quoits apparatus.

## CONCLUSION:

This study shows that yoked prism affects spatial localization and that the effect is dependent upon the task performed. We know localization error will always be in the direction of the prism apex. It is interesting that the degree of spatial shift is dependent upon the task performed because it suggests manipulations of afferent processing centers. Perceptual alterations exist with yoked prism wear forcing patients into new motor-sensory intergration. Yoked prism effects on stereolocalization validate this perceptual shift.

The value of this study is based in the fact that yoked prism profoundly affects patients in optometric vision therapy. The answer as to why is somewhat unclear. I believe yoked prism is powerful because it creates perceptual adaptation. This adaptation causes a central nervous system response. A response that is directed to all the afferent processing centers of the brain.

Yoked prism therapy requires a processing system that needs change. A system which may only need to be nudged a little by forcing visual adaptation. This adaptation stimulates new motor-sensory learning. These may be patients who are recovering from a stroke or they may be an elite athlete.

Future studies in this area should address yoked prism's effects on tonic accommodation and vergence and on connections with perceptual homeostasis. I am particularly interested in yoked prism effects on the locus coueruleus and in visual attentional mechanisms.

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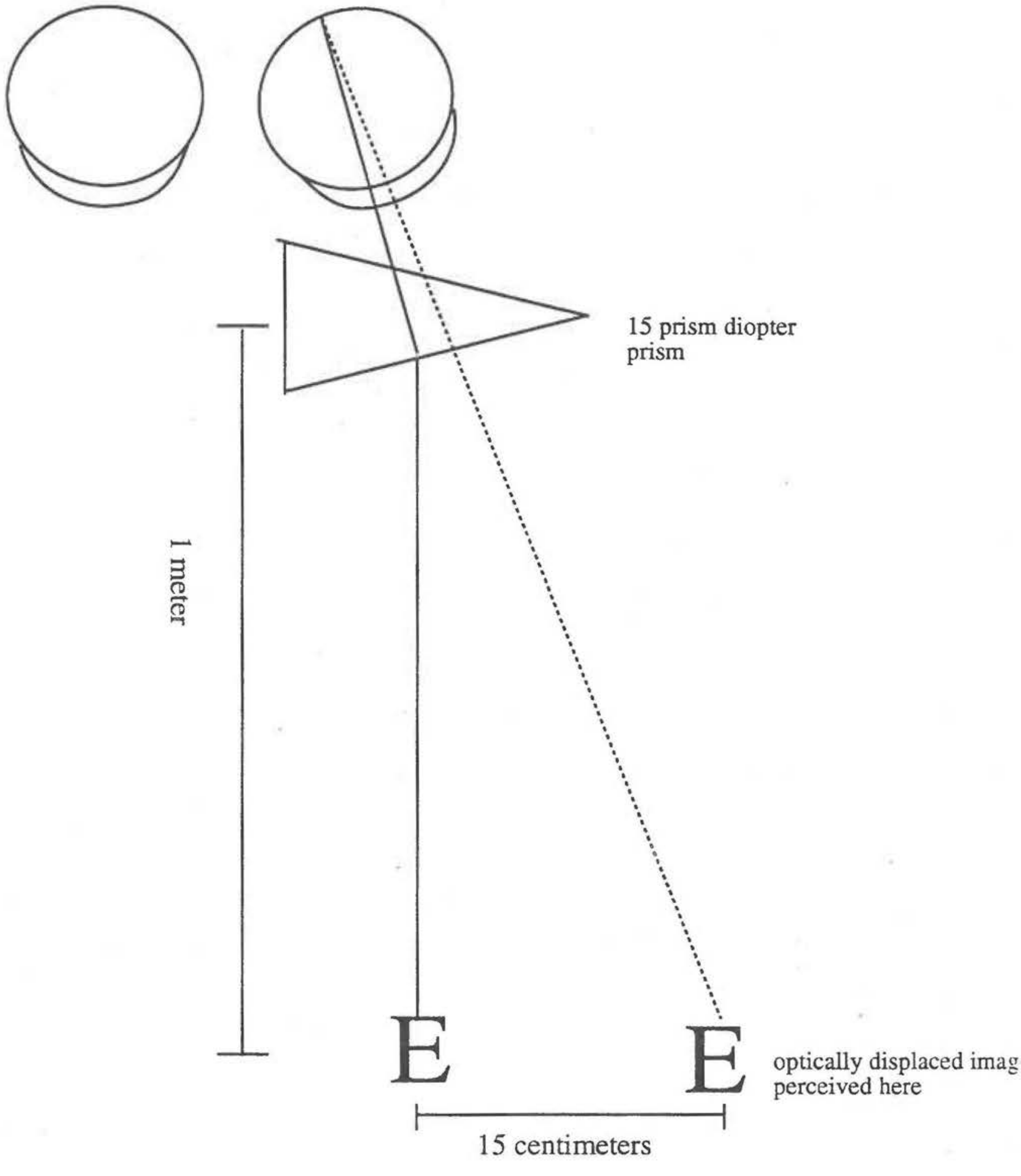
Reference Notes

a. BVAT, Mentor O and O, Inc., 3000 Longwater Dr. Norwell, MA 02061. 1-800 992-7557.
b. Stereo Optical Corp., 3539 N. Kenton Ave. Chicago, IL 60641. 1-800 344-9500.
c. GTVT, 18807 10th PL. W., Lynnwood, WA 98306. 1-800-848-8897or (206) 486-0159.

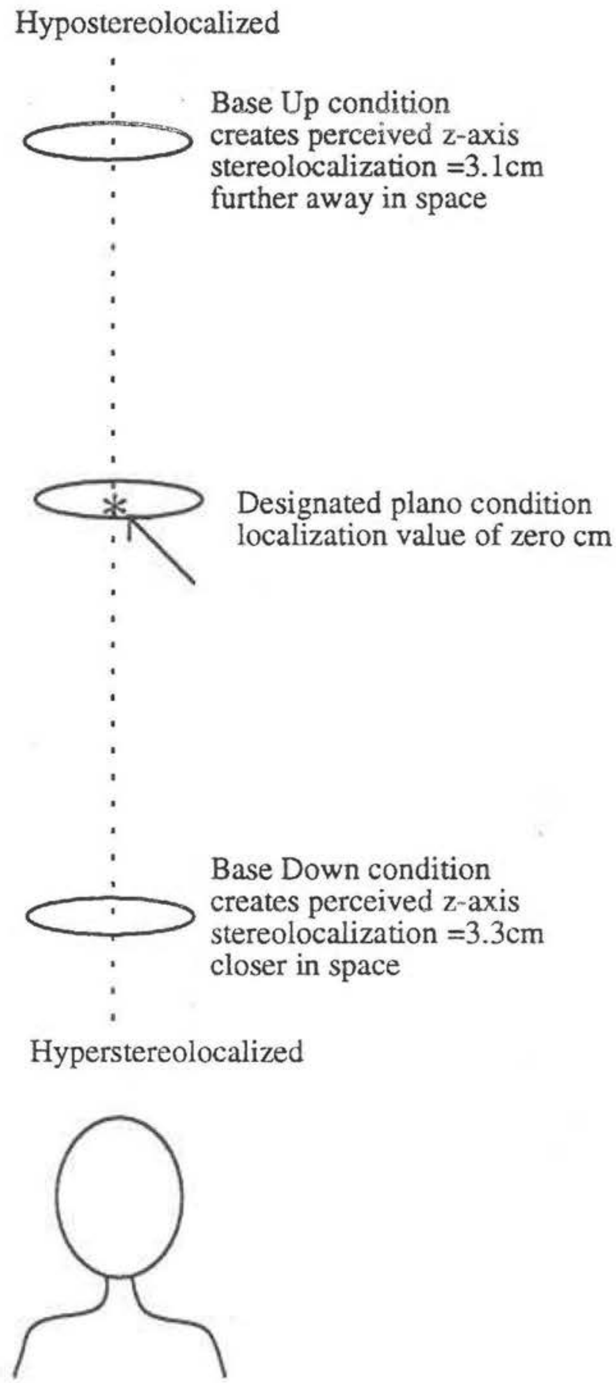
# Appendix 1
# Prism Induced Optical Displacement



# Appendix 2
# Subjective Stereolocalization
# Explanations and Results

Hypostereolocalization and hyperstereolocalization diagram

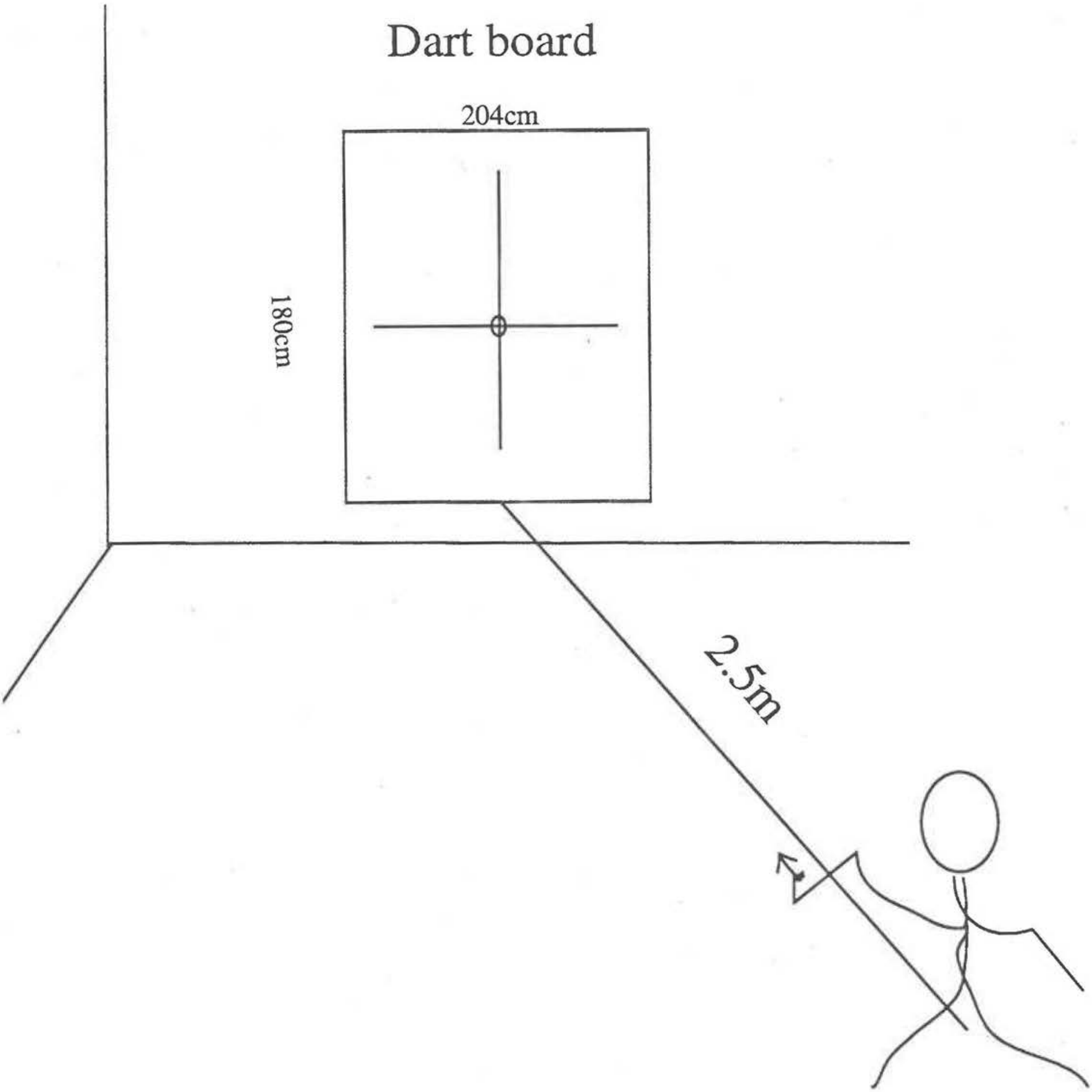
Quoits apparatus results under
two conditions of 15pd vertical
yoked prism wear and a plano condition



# Appendix 3

## The Dart Throwing Task

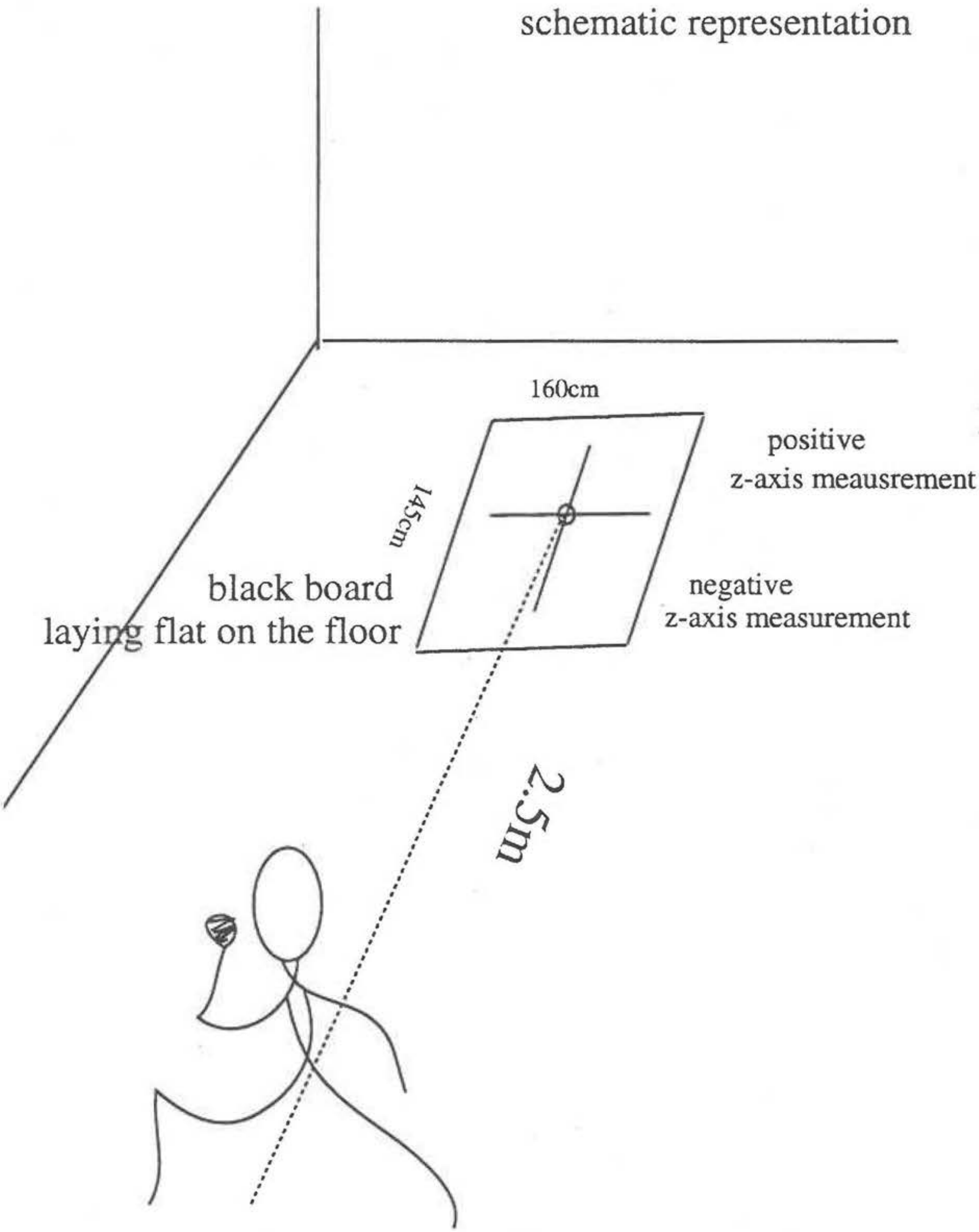
schematic representation



# Appendix 4

## The Bean Bag Toss Task

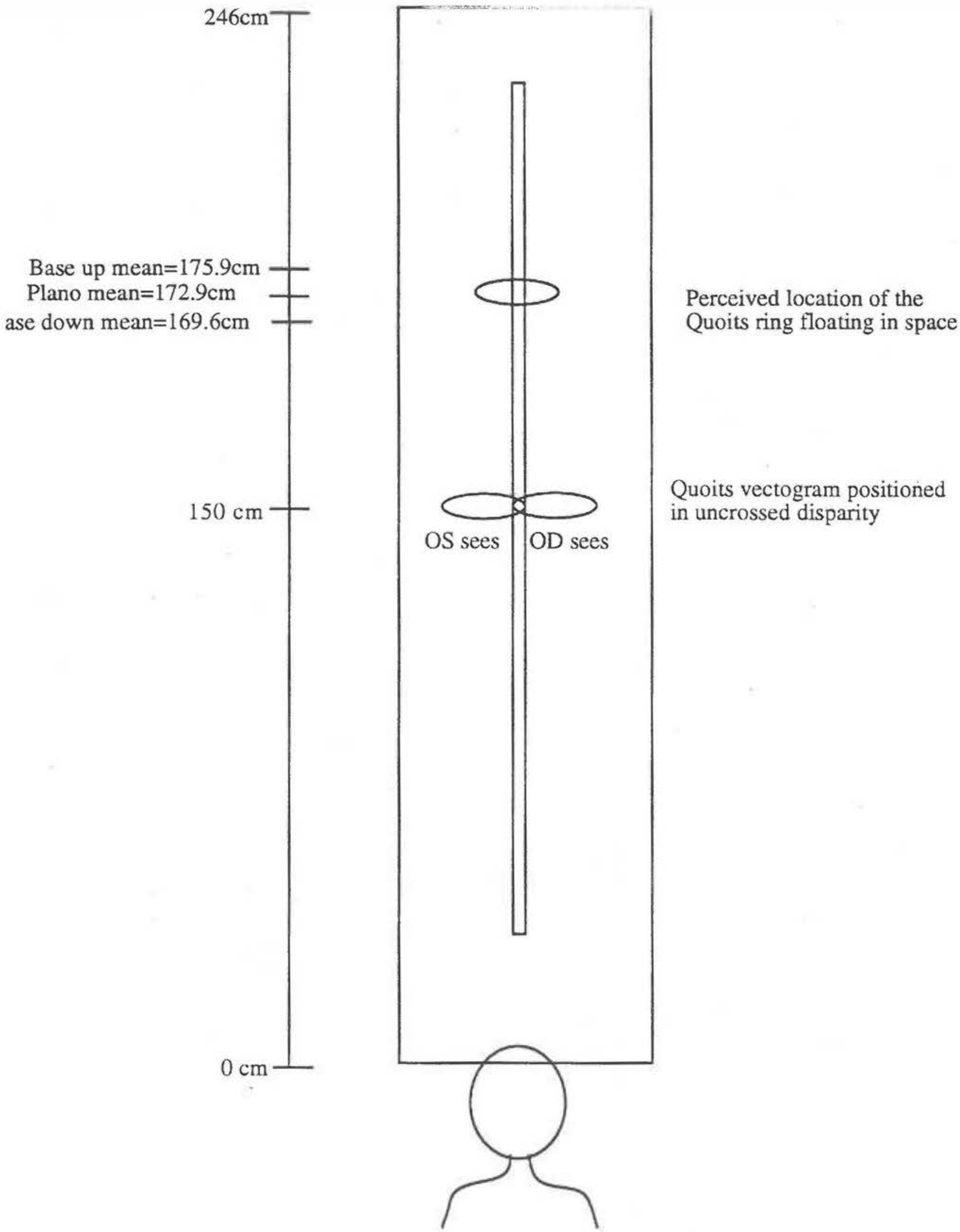
schematic representation



# Appendix 5

# Quoits Vectographic Apparatus

Schematic representation



# Appendix 6

**Protocol**

Protocol For Testing: Effects of yoked prism on spatial location and stereolocalization

*set up apparatus and adjust lighting levels

1. Have subject read and sign consent form.
2. Seat subject in exam chair facing BVAT.
3. Take distance visual acuity OD, OS, OU.
4. Record results.
5. Place LCD goggles on the subject.
6. Give instructions for ring float stereoacuity test.
7. Administer stereoacuity test.
8. Record stereoacuity results.
9. Give instruction set for fixation disparity test.
10. Administer test.
11. Give instruction set for 1.5m cover test.
12. Administer 1.5m cover test
13. Give instruction set for 1.5m superior gaze cover test.
14. Administer 1.5m superior gaze cover test.
15. Give instruction set for 1.5m inferior gaze cover test.
16. Administer 1.5m inferior gaze cover test.
17. Record A/V pattern cover test results.
18. Give 6m Maddox rod phoria instruction set.
19. Take and record Maddox rod phoria.
20. Place polarized glasses on subject.
21. Give instruction set for crossed disparity vectographic SILO/SOLI test.
22. Administer vectographic SILO/SOLI test.
23. Record subjective impression of SILO/SOLI.
24. Take subjects 1.5m pd.
25. Instruct subject to come to dark adaptation lab (room 325)

The sequence of the three tests is determined by subject number. Every five subjects the order of tests will be changed.

Test A Quoits ring stereolocalization test. Randomly determine lens condition by drawing an order out of a hat.

*

26. Give instruction set.
27. Place proper lens on patient.
28. Have subject place chin in chin rest and look through aperture.
29. Subject will verbally indicate in which direction the pointer needs to be moved for alignment.
30. Record measured perception of float.
31. Experimenter will alternate between starting each measurement with pointer +/- 30cm from previously measured floating rings position in space.
32. Run three trials under different lens conditions with three measurements in each trial by repeating steps 27-31.

**Test B** Dart throwing task. Randomly determine lens condition by drawing an order out of a hat.

*

33. Give instruction set.
34. Place proper lens on subject.
35. Standing behind the 2.5m mark the subject will throw five darts at the target.
36. Subject turns around as examiner records dart location measurements.
37. Run five trials under different lens conditions with five measurements in each trial by repeating steps 34-36.

**Test C** Bean bag toss task. Randomly select lens condition by drawing an order out of a hat.

*

38. Give instruction set.
39. Place proper lens on subject.
40. Standing behind 2.5m mark subject will toss five bean bags at the target.
41. Subject turns around as examiner records bean bag location measurements.
42. Run three trials under different lens conditions with five measurements in each trial by repeating steps 39-41.

# Appendix 7

### Informed Consent Form

**A. Title of Project:** Effects of Yoked Prism on Spatial Location and Stereolocalization

**B. Principal investigator:** Dan Hock 359-3977

**C. Advisor:** Bradley Coffey O.D. 357-6151 ext. 2280

**D. Location:** Pacific University College of Optometry, Forest Grove OR.

**E. Date:** August and September, 1994

**1. Description of Project:** A three dimensional floating target is used to quantify subject's depth perception. A measurement of float distance will be made at the point where the observer perceives alignment of a floating ring and a moveable pointer which is controlled by an experimenter. Three measurements will be recorded under three conditions of different lenses.

A spatial location task requiring subjects to throw darts at contrast free target will be used to assess shifts in two dimensional space. Subjects will be asked to throw five darts in each of five sets of conditions.

A bean bag toss task requiring subjects to attempt to hit a target located on a contrast free board is used to assess the z-axis of space. This task does not allow the subject feedback as to accuracy or lack of accuracy of their toss. Subjects will be asked to toss 5 bean bags in each of three conditions. Each subject should expect to spend 20 minutes completing these tasks and an additional 10 minutes for entrance criteria testing.

**2. Description of Risks:**

A) No invasive techniques will be used during the visual exams. Some individuals may briefly experience mild headache, fatigue, nausea, and/ or dizziness as a result of viewing the floating ring and wearing disruptive yoked prism glasses.

B) The procedures require taking on and off glasses, throwing darts, and tossing bean bags. There is a slight possibility that injury could result from these tasks.

**3. Description of Benefits:** This study will serve to add to the body of knowledge concerning yoked prisms and their effects on all dimensions of space. There is credit offered to students in the first year optometry class towards fulfilling a research participation requirement.

**4. Records:** All records of this project will be maintained in a confidential manner and no name-identifiable information will be released.

**5. Compensation and medical care:** If you are injured in this experiment it is possible that you will not receive compensation or medical care from Pacific University, the experimenters, or any organization associated with the experiment. All responsible care will be used to prevent injury.

**6. Offer to answer any inquiries:** The experimenter will be happy to answer any questions that you may have at any time during the course of the study. If you are not satisfied with the answer you receive, please call Dr. James Peterson at 357-0442. During your participation in the project you are not a Pacific University clinic patient; you are a client for the purpose of research and all questions should be directed to the researchers and/or the faculty advisor who will be solely responsible for any treatment (except for an emergency). You will not be receiving complete eye, vision or health care as a result of participation in this project; therefore you will need to maintain your regular program of eye, vision, and health care.

**7. Freedom to withdraw:** You are free to withdraw your consent and to discontinue participation in this project or activity at any time without prejudice to you.

I have read and understand the above. I am 18 years of age or over.

Printed name______________________________

Signed________________________Date________

Address_______________________Phone__________

City__________________________State/Zip__________

Name and address of a person not living with you who will always know your address.

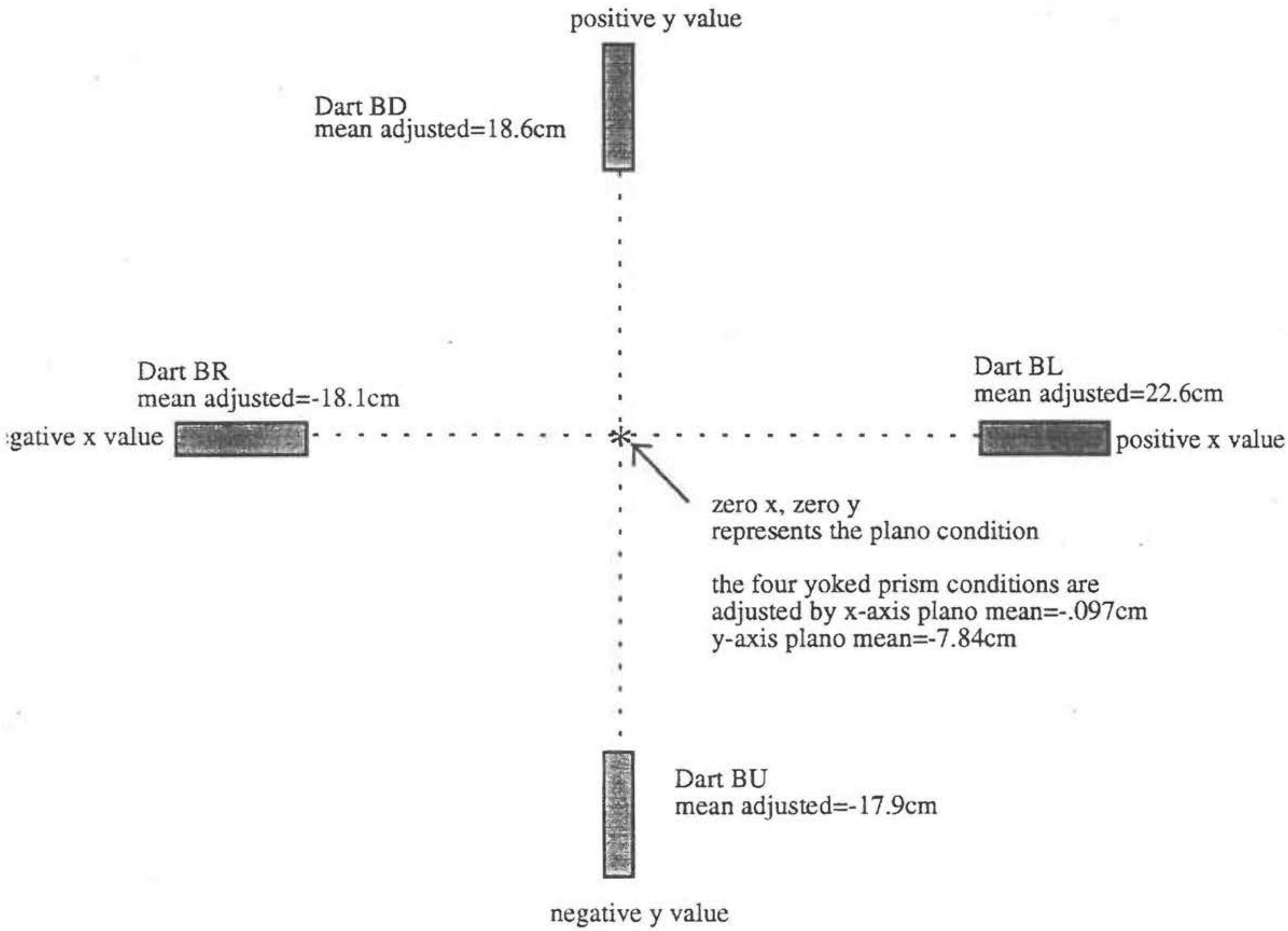
_____________________________________________

_____________________________________________

# Appendix 8

## SUBJECTIVE OPTICAL DISPLACEMENT RESULTS

Dart task completed under four conditions of 15pd yoked prism wear and an x and y-axis plano condition

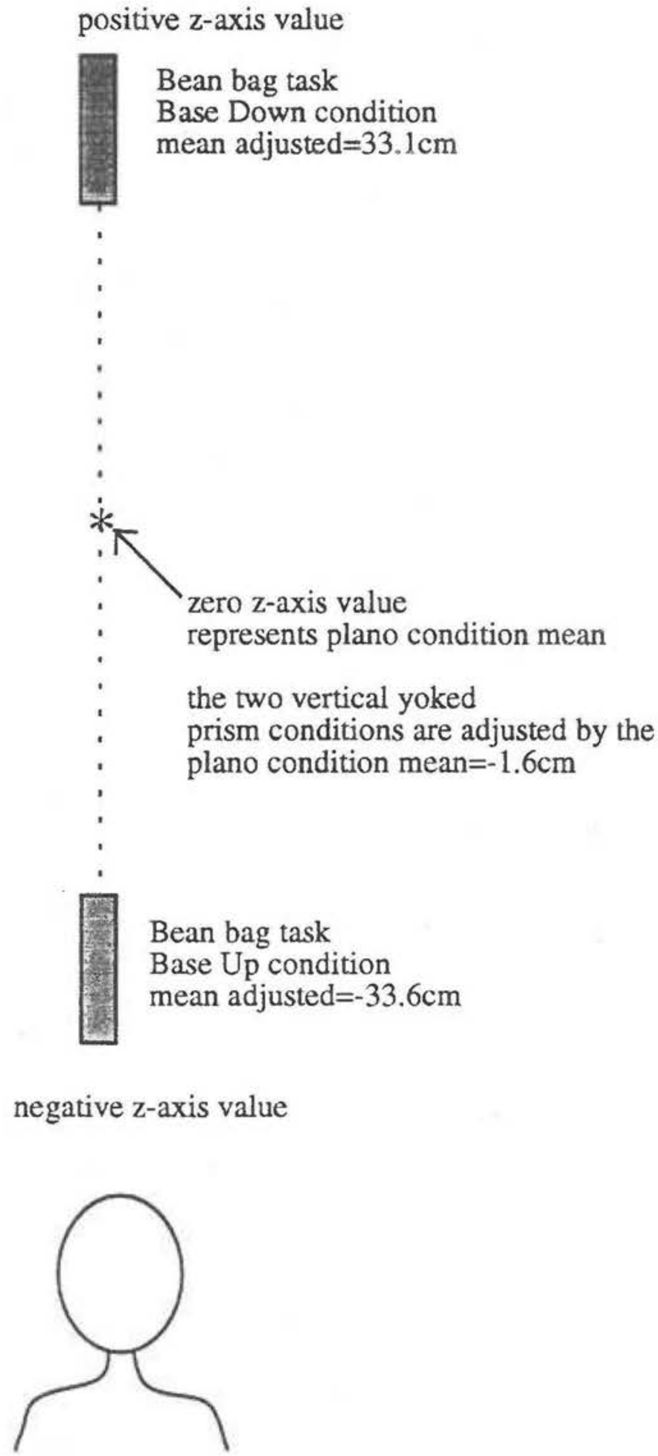


# Appendix 9

# SUBJECTIVE OPTICAL DISPLACEMENT RESULTS

## Z-axis

Bean bag task completed under two conditions
of 15pd vertical yoked prism wear and a
z-axis plano condition



# Appendix 10

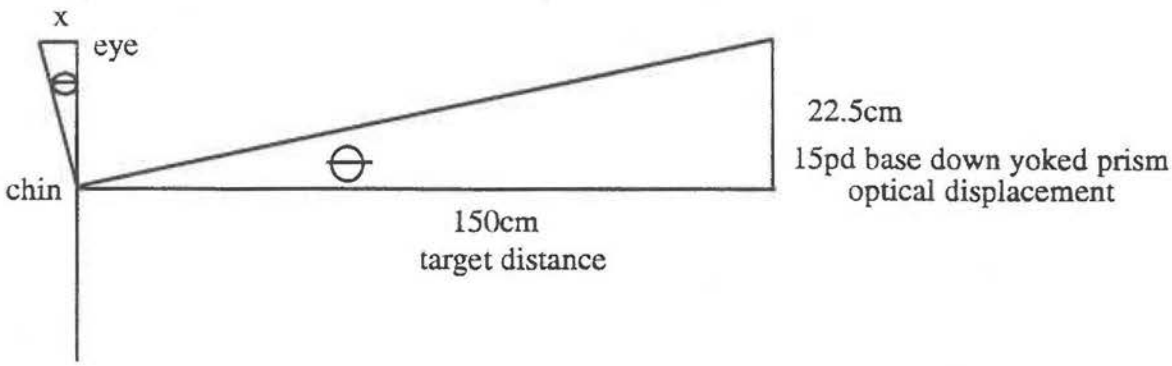
## Significant Differences by Condition

using post-hoc procedures

| | mean difference | Scheffe F-test |
|---|---|---|
| Dt PIY mean vs. Dt BD mean | -18.6 | 41.512* |
| Dt PI Y mean vs Dt BU mean | 17.859 | 38.27* |
| Dt BU mean vs Dt BD mean | 36.459 | 159.497* |
| Dt PI X mean vs Dt BL mean | -22.559 | 56.034* |
| Dt PI X mean vs Dt BR mean | 18.126 | 36.178* |
| Dt Bl mean vs Dt BR mean | 40.685 | 1282.26* |
| Dt BL mean adj vs Dt BR mean adj | 40.685 | 241.788* |
| Dt BD mean adj vs Dt BU mean adj | 36.459 | 202.12* |
| **Bean Bag Loaclization Task** | | |
| BBg PL mean vs BBg BD mean | -33.088 | 72.264* |
| BBg PL mean vs BBg BU mean | 33.574 | 74.4* |
| BBg BD mean vs BBg BU mean | 66.662 | 293.312* |
| BBg BD mean adj vs BBg BU mean adj | 66.662 | 455.092* |
| **Quoits Stereolocalization** | | |
| Q PI mean vs Q BD mean | -3.321 | 24.339* |
| Q PI mean vs Q BU mean | 3.065 | 20.733* |
| Q BD mean vs Q BU mean | 6.385 | 90* |
| Q BD change vs Q DU change | 6.376 | 136.545* |
| SILO vs SOLI | -2.284 | 4.929* |

*significant at $p<0.05$

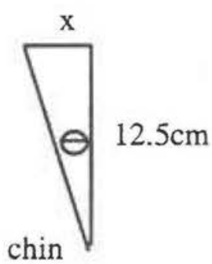
# Appendix 11
# Mathmatical Justification of Perceptual Shift




Frontal parallel plane

$$\text{arc tan } \theta = \frac{22.5}{150} = 8.53 \text{ degrees}$$

Similar triangles are used to find x (the perceptual shift) known are theta and an averaged value of chin to mid pupil=12.5cm




$$8.53 \tan = \frac{x}{12.5\text{cm}}$$

$$x = 1.88\text{cm}$$