EFFECTS
OF
YOKED PRISM
ON
SPATIAL LOCALIZATION
AND
STEREOLOCALIZATION

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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 15Δ horizontal and vertical yoked prisms and plano control lenses, and measurements were recorded assessing the shift of visual space perception in horizontal (x), vertical (y), and the near-to-far (z) axis. Subjects completed visual motor tasks while wearing the different prisms. With visual feedback denied, the yoked prisms produced significant localization errors in the x-, y-, and z-axes. The errors were consistent with the prismatic displacement of visual space, but were less than would be predicted by Prentice's Method. Vertical yoked prism also had a significant effect on stereolocalization accuracy, as measured using the Quoits vectogram in a special apparatus. Base-up yoked prism caused subjects to stereolocalize further away in space and base-down yoked prism caused subjects to stereolocalize closer in visual space, both results in reference to the plano control condition. These results provide evidence of alterations in visual space perception associated with wear of yoked prism.

Key Words

yoked prism, spatial localization, stereolocalization, crossed and uncrossed disparity, depth perception

Yoked prism is defined as a pair of prismatic spectacle lenses of equal power with bases oriented the same direction before each eye.[1] Yoked prism causes the apparent location of viewed objects to be shifted in the direction of the prism apex. Hence, if base down yoked prism is placed before the eyes of an observer who is fixating a target, the target will appear to move upward. The amount of linear upward deviation of the target is proportional to both the power of the prism and the distance between the prism and the viewed object (Prentice Method). The normal observer's adaptation to the prism-displaced image involves an ocular movement to align the retina with the new stimulus position. The corresponding adjustment in the efferent command signal to the extraocular muscles changes 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 in visual motor function can occur.

The visual perception of space is known to be affected by binocular vergence factors[2-7] and this fact is frequently utilized in vision therapy practice, as when asking patients to localize binocular targets in space under different degrees of forced vergence. The role of yoked prism-induced conjugate changes in eye position and related effects on spatial perception has attracted increased interest from clinicians during the past twenty years. Although the optometric literature on yoked prism-induced changes in spatial perception is rather sparse, there is substantial literature to be found in other fields, principally neuroscience and motor behavior. Probably the earliest work in the area can be traced to Helmholtz who in 1867 described spatial localization errors due to the lateral displacement of prism.[8] Early twentieth century studies involving the application of distorting prism goggles to the study of visual adaptation is reflected in the work of Stratton, Erismann, and Gibson.[9] These early perceptual adaptation studies were valuable because they proved that visual perception can be altered and that human subjects can learn and adapt to new visual environments.

Many modern studies of yoked prism have focused on the characteristics of visual-motor adaptation after symmetrical prisms have been applied and again when they are removed. In the non-optometric literature, the term "prism adaptation" is typically used to refer to visual motor reorganization that occurs with yoked prism or monocular prism. This use of "prism adaptation" to refer to visual spatial effects of prism is in distinction to the optometric use of the term to connote changes in horizontal or vertical vergence posture associated with wear of asymmetrical prism (base-out, base-in, or monocular base-up or down). It should be noted also that the term "yoked prism" seems uniquely optometric. The word "yoked" is not used to describe the symmetrical prisms used in the non-optometric studies mentioned in the next paragraph.

It has been demonstrated that eye-hand response speed is slowed during the visual motor process of adaptation to prism, but returns essentially to normal after adaptation is complete.[10] Although response speed normalizes fairly quickly with repetition, spatial localization errors remain over a longer time course. When the spatial localization error has been corrected through adaptation based upon visual feedback, a "negative aftereffect" occurs when the prisms are removed, requiring a readaptation by the subject to regain baseline accuracy.[11] Visual motor adaptation is virtually nonexistent if visual feedback is denied, and is slowed significantly if visual feedback is delayed[12] or if motor responses are intentionally slowed.[13] The authors' interest in avian behavior causes us to note evidence suggesting that barn owls, in contrast to primates, seem to have very limited capability to make visual motor adaptations to yoked prism. Further, the owls also undergo very little readaptation when prisms are removed.[14]

In addition to the effects on spatial localization in two-dimensional space, yoked prism has been shown to affect the position of the body's center of mass when standing.[15] These effects on center of mass appear to be of very brief duration in normal human subjects.[16,17]

Yoked prism effects on spatial relationships have made them a valuable tool in the training/therapy practices of behavioral optometrists. The Optometric Extension Program has published clinical monographs by Horner,[18] Kaplan,[19] Kraskin,[20] and Valenti[21] that advocate yoked prism as having both diagnostic and therapeutic uses. According to these reports, patients using vertical yoked prism have reported decreased asthenopia, increased reading comprehension, decreased motion sickness, improved peripheral awareness, and increased sports performance.

Kaplan[19] 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 can cause a perceptual effect known as SILO, an acronym for "smaller in larger out."[22] The SILO responder prioritizes vergence as a cue for perception of distance. This person perceives an object to be moving closer when convergence is stimulated by base out prism because she or he "knows" from previous experience that when she or he converges it means she or he is looking at an object moving closer.[23] This interpretation reveals input system structure primarily reliant upon the vergence system. SOLI responders rely predominantly on retinal angular subtense (image size) and perceive smaller objects as being further away in space, a perceptual outcome that is consistent with real world experience.

The oculomotor system has been shown experimentally to contribute to spatial localization.[24,25] 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 yoked prism affects the version system. It is not known what effect yoked prism 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.

Yoked prism causes a noticeable subjective shift in the spatial localization of visual information.[26] It is not known whether yoked prism has any predictable effect on stereolocalization. Stereolocalization refers to the ability to make a z-axis judgment of where a target appears to be when fusion occurs, and is related to the concept of physiological diplopia.[27] This measurement can be accurately achieved using a variable vectographic apparatus developed by Fredrickson, Gorham, and Kohl.[27]

Further experimentation regarding yoked prism effects on spatial localization and stereolocalization were needed. This study was designed to quantify the effects of both horizontal and vertical yoked prism on horizontal (x), vertical (y), and near-to-far (z) dimensions of visual space. Experimental conditions were controlled so that subjects were denied visual feedback as a means for correcting inaccurate spatial localization judgements. The effects of vertical yoked prism on stereolocalization measurements were also examined. It was hypothesized that there exist not only x-, y-, and z-axis localization shifts with vertical yoked prism, but that a stereolocalization shift is created as well. Are spatial localization and stereolocalization influenced by vertical yoked prism? 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 with ages ranging from 21 to 42 years were subjects. Subjects were tested during their first two weeks in the College of Optometry and were naive as to effects of yoked prism on vision. Initial evaluations were done on each to exclude those with binocular dysfunction. All subjects met the following inclusion/exclusion criteria:

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

Three additional measurements were taken to assist in later description of the subjects' responses:

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[b] viewed at 50cm. Subjects were asked first to describe any *size change* they noticed in Topper as crossed disparity was increased. If they responded "smaller" the disparity was returned to zero. Subjects were next asked to describe any *apparent change in Topper's location* as crossed disparity was again 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.

PROCEDURE

Yoked prisms

The plastic lenses and prisms used were 66mm in diameter with front base curves of +6.75D. One pair of plano lenses was utilized as a control condition. The plano lenses had a center thickness of 6.0mm to match the overall mass of the prism lenses. The power of the yoked prisms was 15Δ. The yoked prism or plano control lenses were mounted using Velcro dots to plastic goggles.[c] The plastic goggles were worn over the subject's habitual lens Rx (if any).

X and Y-axis spatial localization

A visual feedback-free task required subjects to throw black darts at a target located on a black board in a dimly illuminated room. Subjects were tested in five conditions: horizontal yoked prism (base-left (BL) and base-right (BR)), vertical yoked prism (base up (BU) and base-down (BD)), and plano control lenses. A 2cm diameter yellow circle was centrally positioned on a black sheet of fabric which was draped over a corkboard mounted vertically on a wall. Subjects were instructed to throw black darts at the yellow circle target. Subjects threw five darts in each of the five prism conditions from a distance of 2.5m. Order of prism conditions was counterbalanced to minimize learning or adaptation effects. The testing environment was controlled so that subjects were unable to see the final position of each dart after it was thrown. Room illumination was sufficient to see the small yellow target, but too dim to provide visual feedback of the darts' final endpoint. The dart in flight, and once it stuck in the black board, was invisible to the subject. Figure 1 is a cartoon of the experimental set up. After each prism condition, an experimenter measured the spatial localization errors while the subject looked away. For horizontal yoked prism, errors to the left or right of center were recorded as the x-axis intersect values. For vertical yoked prism, errors above or below center were recorded as the y-axis intersect values.

Z-axis spatial localization

A similarly designed task required subjects to toss black bean bags while wearing vertical yoked prism (BU and BD) in order to quantify subjective z-axis distance perception changes. A 2cm 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 beanbags made of the same fabric as that which covered the board. Subjects stood behind a line on the floor positioned 2.5m from the center of the yellow target. Again, visual feedback was eliminated by the black beanbags not being visible on the black board where the target was located. Room illumination was sufficient to see the small yellow target, but too dim to provide visual feedback of the beanbags' final endpoint. Subjects tossed five beanbags in each of the three prism conditions. Testing order of the prism conditions was randomized from subject to subject. Figure 2 is a cartoon of the experimental set up. After each prism condition, an experimenter measured the initial landing position of each beanbag while the subject looked away. Errors beyond the target dot were recorded as the positive z-axis intersect value; errors closer than the target dot were recorded as the negative z-axis intersect value.

Stereolocalization

The scope of this part of the investigation was limited to the effects of vertical yoked prism on stereolocalization. The target was the Quoits variable vectogram[b] viewed at a distance of 1.5m in an apparatus designed by Fredrickson, Gorham, and Kohl[27] (see Figure 3). Norms for stereolocalization accuracy on the apparatus were available for both crossed and uncrossed disparities based upon their work. The norms indicate that subjects localize very accurately for both disparity types when compared to the mathematically calculated localization point. A difference of 1% or less exists between the

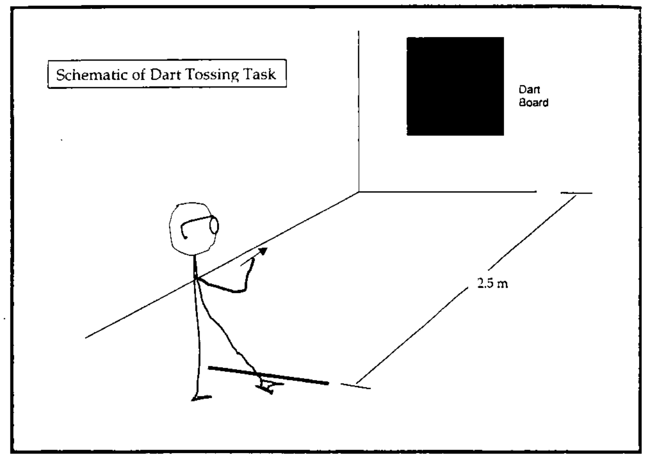

Figure 1. Subjects stood 2.5 m from the target mounted on a wall. Black darts were thrown toward a visible yellow central dot. Room illumination was sufficient to see the yellow target, but too dim to provide visual feedback of the darts' final endpoint.

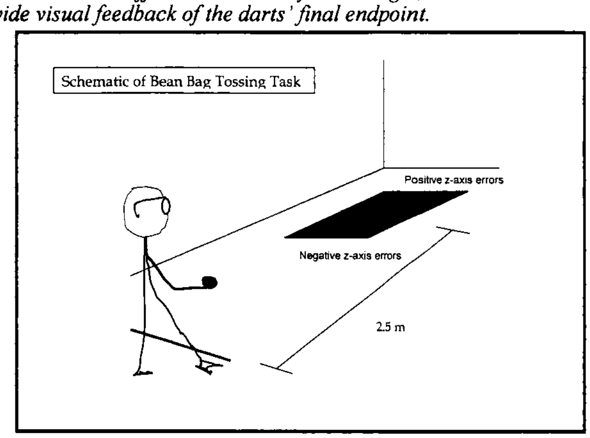

Figure 2. Subjects stood 2.5 m from the center of the target on the floor. Black beanbags were thrown toward a visible yellow central dot. Room illumination was sufficient to see the yellow target, but too dim to provide visual feedback of the beanbags' final endpoint.

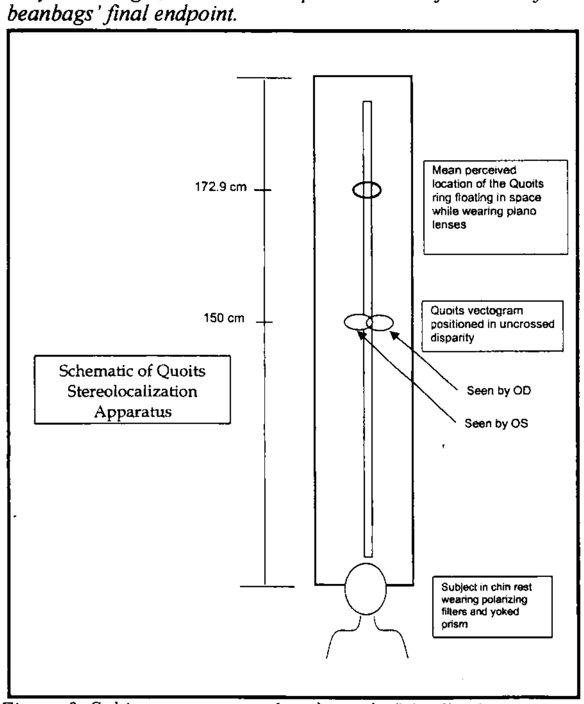

Figure 3. Subjects were seated at the end of the Quoits apparatus and used a remote-controlled pointer to identify the perceived location of the fused, floating Quoits ring. The mean location of the fused Quoits is illustrated.

Table 1. Descriptive data for the magnitude of spatial localization error on the dart tossing task portrayed by yoked prism condition. Sign convention follows Cartesian coordinates.

Dart prism condition	adj. mean (cm)	std. dev. (cm)	std. error (cm)
Base Down	18.6	11.5	2.0
Base Up	-17.9	8.3	1.4
Base Left	22.6	10.4	1.8
Base Right	-18.1	11.1	1.9

Table 2. Descriptive data for the magnitude of spatial localization error on the beanbag tossing task portrayed by yoked prism condition. Positive values indicate overestimation of target distance; negative values represent underestimation.

Bean Bag prism condition	adj. mean (cm)	std. dev. (cm)	std. error (cm)
Base-Down	33.1	15.7	2.7
Base-Up	-33.6	13.9	2.4

Table 3. Descriptive data for the magnitude of stereolocalization error on the Quoits task portrayed by yoked prism condition. Base up yoked prism caused stereolocalization to move beyond the plano condition; base down yoked prism caused stereolocalization to move closer than the plano condition.

Quoits prism condition	mean distance from subject (cm)	std. dev. (cm)	std. error (cm)
Plano	172.8	3.5	0.6
Base-Up	175.9	3.0	0.5
Base-Down	169.6	3.9	0.5

calculated response and the real, measured response.[27]

The Quoits variable vectographic apparatus was originally created to quantify subjects' stereolocalization and to compare these results to what is mathematically calculated by trigonometry and disparity measurements. A 9mm uncrossed disparity was used in the present study because it was found to be the most accurately localized disparity setting.

Subjects' stereolocalization was measured in real space using a Quoits vectographic target suspended by monofilament line in a transparent holder. Two opposing polarized targets that are 9.3cm diameter rings comprise the Quoits target. The 9mm uncrossed disparity corresponds to a fusional demand of 1.2Δ base-in. The subject wore polarized filters while seated and positioned in a chin rest at the end of the optical bench. The distance between the Quoits vectogram and the chin rest was 1.5m.

Peripheral localization cues were minimized by using a plain white cloth curtain that completely surrounded the optical bench and apparatus. Additionally, a black sheet was draped over the optical bench itself. The sheet had a thin linear cut in it to allow a vertical black pointer to be moved to a position immediately below the perceived "float" position of the fused Quoits rings. The pointer was attached to a movable cart that was controlled remotely by the experimenter. The cart had a horizontal pin marker above a mm scale that allowed the vertical pointer position to be measured quickly and easily. The subject was instructed to verbally indicate when the black pointer was directly aligned beneath the perceived floating target. The subjects were encouraged to refine their judgements as needed until they were certain of alignment. Three measurements were run in each of the three randomized prism conditions (BU, BD, plano control). The vertical pointer was moved ±30 cm from the previous setting between trials.

RESULTS

X and Y-axis spatial localization task – dart tossing

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 (adjusted mean). 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 prism. Scheffe's post hoc analysis revealed that all four prism conditions differed from the plano control condition. These data are shown in Table 1.

Z-axis spatial localization task – bean bag tossing

Changes in the tossed beanbags' 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 (adjusted mean). 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. Scheffe's post hoc analysis revealed that both prism conditions differed from the plano control condition. These data are shown in Table 2.

Stereolocalization task -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=0.0001) by prism condition were determined using repeated measures ANOVA. Scheffe's post hoc analysis revealed that both prism conditions differed from the plano control condition. These data are in Table 3.

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. However, subjects who were SOLI responders (n=7) had significantly larger (p<0.05) stereolocalization errors than did their SILO responding counterparts (n=27). In the base down condition, the SOLI responders demonstrated stereolocalization errors 80% greater than the SILO responders did; in the base up condition, the SOLI responders demonstrated stereolocalization errors 43% greater than the SILO responders did.

DISCUSSION

X and Y-axis spatial localization task – dart tossing

On average, for the four yoked prism trials, mean adjusted localization error was found to equal 19.3cm for the dart task done at 2.5m with 15Δ yoked prism. The results appear fairly symmetrical comparing BR, BL, BU and BD. The optical computation of target displacement for 15Δ yoked prism at a distance of 2.5m is 37.5cm. Under these testing conditions, subjective impression of space change was 51% of what would be predicted strictly by the optics, probably due to the mitigating effect of residual egocentric localization cues; i.e., subjects were aware that what is directly in front of them does not change when prisms are used to create visual displacement.

Z-axis spatial localization task – bean bag tossing

The average localization error on the bean bag tossing task while wearing 15Δ vertical yoked prism equaled 33.3cm. The results of this task are symmetrical comparing the effect of BD to BU. Assuming an average distance of 1.75m between the floor and the center of the pupils of the eyes for our subjects, the 15Δ BD yoked prism caused an optical shift of the target position of 1.02m further away. The 15Δ BU yoked prism caused an optical shift of target position of 0.66m closer. Subjects' mean localization error for BD yoked prism was therefore 32% of the calculated optical error. For BU yoked prism the mean localization error was 51% of the calculated optical error, identical to the mean localization error found with the dart tossing task.

Stereolocalization as measured with the Quoits apparatus

The calculated position of stereo float using the Quoits apparatus can be determined based upon similar triangles using this equation:

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

mean interpupillary distance = 58.7mm
target disparity = 9mm
chin position to vectogram = 150cm
X= calculated distance of stereoscopic float behind Quoits vectogram; X = 27.14cm

Calculated stereo float position =
150 cm + 27.14cm = 177.14cm

The calculated stereolocalization position of 177.14cm differs from the empirically determined mean value through plano lenses of 172.8cm, indicating that as a group, the subjects perceived the floating Quoits ring to be closer than its calculated position while wearing plano lenses. Both vertical yoked prism conditions produced significant and symmetrical changes in stereolocalization. BD caused subjects to stereolocalize 3cm closer and BU 3cm further in space compared to the plano condition. At the testing distance of 1.5m, there exists a 6cm difference between BU and BD stereolocalization values. The effects of yoked prism on stereolocalization have been questioned clinically, but no experimental data previously existed to clarify the issue.

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 a temporary shift of the body's center of mass backwards, in the direction of the heels.[16] This shift may create an inaccurate perception of being further from the target. Such a perceptual shift could cause subjects wearing BD yoked prism 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 mass.[16] 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.

A similar interpretation of the data can be derived based upon a difference in perceptual information provided by extraocular muscle activity and felt head position. The subjects were stabilized in the chin rest when measurements were being taken, yet the extraocular muscles were required to adjust for the prismatically displaced image. The adjustment the extraocular muscles made in the absence of a change in head position created a mismatch between visual and proprioceptive-kinesthetic afferent information. The localization error due to this mismatch can be predicted and estimated using simple trigonometry and similar triangles (see Figure 4). 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 error strictly from the yoked prism effects on the extraocular muscle activity can be approximated to 1.88cm, a value that is 63% of the 3cm effect we found using the Quoits apparatus.

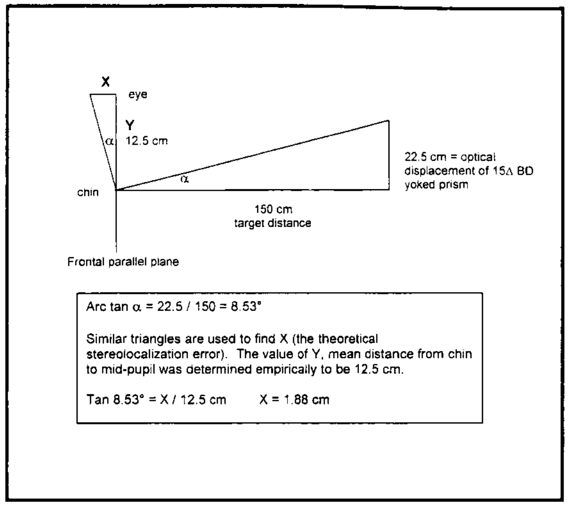

Figure 4. Method of calculation to estimate magnitude of stereolocalization error due to mismatch between visual and proprioceptive- kinesthetic afferent sensory information.

CONCLUSION

This study shows that yoked prism, in the absence of visual feedback, affects spatial localization and that the effect is dependent upon the task performed. Localization errors are in the direction of the prism apex for tasks involving spatial judgements on the x-, y-, and z-axes. For a given yoked prism power, spatial localization errors are similar for z-axis judgements and for x- and y-axis judgements, relative to the calculated error due to optical displacement by the prism. The one exception to this generalization is that BD yoked prism caused a smaller relative error than did BU yoked prism on the z-axis localization task. Vertical yoked prism affects stereolocalization as well, with BU yoked prism causing hyperstereolocalization and BD yoked prism causing hypostereolocalization. These results support the clinical notion that perceptual and spatial alterations occur with yoked prism wear forcing patients into new sensory-motor interaction.

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Date accepted for publication:
September 5, 2000