Stereolocalization: A comparison of crossed and uncrossed disparities

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STEREOLocalization:
A Comparison of
Crossed and Uncrossed Disparities

By

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And

Nathan W. Gorham

A thesis submitted to the faculty of the
College of Optometry
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Paul Kohl, O.D.
Hannu Laukkanen, O.D.
STEREOLOCALIZATION:
A COMPARISON OF CROSSED AND UNCROSSED DISPARITIES

AUTHORS:

BRADLEY A. FREDERICKSON
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The Stereolocalization ability of fifty subjects was assessed using a Quoits Variable Vectographic Target. Measurements of stereolocalization were taken at seven different disparity settings. Subject accuracy under crossed and uncrossed conditions was compared as well as a comparison of empirical and theoretical localizations for each disparity. It was found that under all conditions subjects were accurate to within 1% or less of the mathematically derived location of the image. There was also found to be a statistically significant difference between two of the matched crossed and uncrossed disparity responses, but the differences were probably clinically insignificant.

INTRODUCTION

In the practice of optometry the assessment and evaluation of binocularity is an important aspect of eye care. One component of binocularity is depth perception. Depth perception is commonly tested with devices using polaroid and anaglyph material; the Stereofly, Stereoreindeer and the Randot are just a few examples. These tests assess one aspect of depth perception, stereoacuity, which is the minimum angle subtense detectable between two objects displaced in space. The polaroid stereopsis testing devices incorporate the use of polaroid glasses in which commonly the right half of the paired target is seen only by the left eye and the left half of the target is only seen by the right eye. This condition gives the
illusion that the target is floating toward the viewer, relative to the plane of the display.

Another aspect of depth perception, perhaps even more important than stereoacuity, is where a target's location is perceived within a stereodisplay. This measurement of perceived target location is termed stereolocalization. Optometrists, both in testing and training situations, often ask the patient, on a qualitative basis where the target is located. These procedures, using devices such as Vectograms and Tranaglyphs, are utilized on a regular basis in the visual training environment.

The Stereo Optical, Quoits Ring Vectographic target used frequently in orthoptic training for vergence ranges with stereo feedback, consists of two transparent pieces of plastic with a polarized picture of a ring of rope imprinted on each piece (see Fig. 1). Each of the two pictures has an opposite orientation of polarization in order that each eye sees only one of the pictures. (See Figure 2.) To induce a disparity between the two images, creating a stereo effect, the two pieces are simply slid apart within a plastic holder. For individuals with a normal binocular system, and with the use of polaroid glasses, the Quoits Ring target will create the illusion that a single circle of rope is floating either in front or behind the transparent holder, depending on which type of disparity is induced, crossed or uncrossed.

This phenomenon of depth perception while using stereodisplays is also used in the entertainment industry. Examples of this are 3-D movies, 3-D comics and the like. In all of the entertainment industry's presentations the crossed disparity (where
the image floats in front of the plane), is used. The uncrossed situation (where the image floats behind the plane) is not employed for it has been noticed that it is more difficult for the visual system to perceive "float" behind a physical barrier, such as a movie screen or a page, than when floating out toward the observer in free space.

Little research has been done to quantify the accuracy of stereolocalization. Some work related to this has been established by Henessey and Leibowitz in their experimentation on the Ponzo illusion, in which they found a greater stereoscopic displacement under crossed conditions.\(^1\) Although not directly related to this study, Dr. Willard Bleything demonstrated how convergence and accommodation, through the use of base out prism and minus spherical lenses, can affect stereolocalization and apparent size.\(^2\)

In this study we will quantify the accuracy of human stereolocalization with a commonly used vectographic target utilized in vision training and testing. The testing conditions used will contain few cues as to actual image distance by eliminating physical barriers, and limiting monocular and peripheral cues to depth. Assessment of measurable differences in accuracy between stereolocalization induced by crossed and uncrossed disparities and comparison of localization to the mathematically predicted model will be analyzed.

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Knowledge of norms for stereolocalization both for crossed and uncrossed disparities will be useful for the clinician in establishing expected for patients when employing such targets.

PATIENT SELECTION AND METHODS:

Most of the fifty subjects chosen for this study were first and second year optometry students and had little to or knowledge of the phenomenon associated with vectographic targets. The subjects were required to have minimum near base-in and base-out ranges of 8 and 10 prism diopters respectively measured in phoropter. Also required were monocular visual acuities of at least 20/30 at distance and near, and a stereoacuity of 40 arcseconds on the Randot stereogram three ball test.

The stereolocalization of each subject was measured in real space using a Stereo Optical Quoits Vectographic target suspended by clear fishing line in a transparent plastic holder. The Quoits Ring Vectographic target consists of two transparent pieces of plastic with a polarized rope picture imprinted on each piece. Each image is round, and 9cm in diameter. The holder was suspended over a table and track device with 1.5 meters left behind and in front to allow room in which the image could "float" in real space. The subject was seated 1.5m from the target with their chin and forehead held in place by a head rest, clamped to the end of the table. Peripheral cues were minimized by using a plain white cloth curtain which completely surrounded the table and apparatus. Additionally, a
piece of plain white poster board was put around the area where the subject viewed the target, so as to screen the periphery. (See Fig.3)

In order to measure perceived "float", subjects were asked to instruct the tester to alter the position of a moveable pointer. The tester was told to move it closer or further away to put the pointer "as close to the perceived floating ring as possible.". (See Figs. 4 and 5). The pointer, a 3/16" dowel painted flat black, was mounted on an adjustable rolling apparatus which moved along a track. The moving cart also had a needle attached perpendicularly to it which pointed to a three-meter measuring stick mounted on the edge of the table. This allowed the direct measurement of the subject's perceived "float." (the distance from the plane of the actual target to the "floating ring" (See Figs. 6 and 7).

This apparatus also moved the pointer vertically (up and down) to counter the perceived SILO effect as the vergence demand was changed. The SILO effect, an acronym for "smaller in larger out" was one problem that had to be addressed. As the disparity for an anaglyphic or vectographic target is increased, the crossed direction creates an image which appears paradoxically smaller, though it appears closer, and the uncrossed disparity image appears larger though it appears farther away (See Figure 2). Had the pointer been at a fixed "up/down" level, the floating rings would have been perceived to be closer or further from the pointer depending on the disparity, and could be used as a depth cue. To engineer for this, the pointer had to be gradually adjusted to follow the position of the perceived ring's edge, whether lower or higher depending on the disparity and the corresponding perceived size
change of the target. (See Figs. 6 and 7.) The apparatus mentioned above contained a gearing apparatus which raised and lowered the pointer as it moved respectively forward and backward along the track. It, too, was masked by black paper so as to minimize peripheral cues. (See Fig. 8).

Using a millimeter ruler the target separation was physically measured on the Quoits Vectogram and then scribed along the edge of the transparency. In this way each of the three crossed and uncrossed disparities were kept constant throughout the testing. Two measurements were taken for each of the seven disparities; zero, six, nine, and twelve millimeters for the crossed and uncrossed conditions. These disparities corresponded to 0, 0.4, 0.6, and 0.8 prism diopters of vergence demand at the 150 cm test distance. The measurements were recorded in centimeters from where the subject perceived the floating image and the plane of regard (the Quoit's Vectogram).

The total luminance on the Quoits ring target was 3.05 cd/m², as measured with the J6523-21o Narrow Angle Luminance Probe. The test object angle was 3.24 degrees at a distance of 1.5 meters.

After each subject was seated in the chin rest, they were instructed to tell the examiner which direction to move the pointer until it was aligned at the same location as the perceived floating ring. Minor adjustments were made to the pointer location until the subject was certain that the pointer was precisely in the same plane as the ring appeared to float. Two presentations at each disparity setting were made, each disparity setting being randomly selected so subject anticipation was not a factor. Between each presentation the
subject's view was occluded while adjustments were made to the Quoits Vectogram, and the rolling pointer mechanism was returned to the plane of the vectogram. An example reading would proceed as follows; occluder removed from subjects view and image is seen; subject asked to instruct tester to move the pointer to exactly where they see the ring floating; subjects view occluded and measurement taken of pointer location; pointer returned to actual plane of target and adjustment made to vectogram, if required, to a new disparity, and the process repeated until two trials for each disparity were completed.

The empirical data were then compared to the mathematically derived stereolocalized float distance for each disparity (where they theoretically should localize the target). The mathematical calculations were performed using a trigonometric method, variables being; target disparity, interpupillary distance and the distance between the actual target and the observer (See Figure 9). A computer program on Macintosh Excel was utilized to calculate the disparities according to each of the interpupillary distances encountered for each disparity. Each of the pairs of measurements taken for each disparity were averaged and compared with the theoretically derived distance to see if there was a statistically significant difference between the accuracy of the crossed and uncrossed disparities. Measurements of perceived float and theoretical float distance were changed to Meter Angles, which provides a relationship that is linear and can be easily compared using parametric statistics. (A meter angle is the reciprocal of a meter and used as a measure of the distance from the person to the
perceived or theoretically derived floating target, in inverse meters)
A paired t-Test was utilized to compare the averages of theoretical and empirical float distances for the crossed (base-out) and uncrossed (base-in) findings for each of the three target separations (12mm, 9mm, 6mm). Mean differences between empirical and theoretical data was analyzed for each of the disparity conditions. A t-test to compare theoretical and empirical data for each disparity was employed.
RESULTS

Since each theoretical float is dependent on individual interpupillary distances, each theoretical calculation was derived taking each person's interpupillary distance into account. Therefore, since the results depend on a person's interpupillary distance it was decided to report any group findings based on the average interpupillary distance of all the subjects. The interpupillary distances were averaged with a mean found to be 61.34mm. The mean theoretical and empirical distances (distance from the observer to the "floating ring") were calculated for each of the seven disparities using the study population's mean PD. Means were calculated in meter angles since meter angles could be compared in a linear relationship between crossed and uncrossed conditions, and between theoretical and empirical distances. All subjects showed a tendency to underestimate the location of the ring when compared to the theoretically determined location for both crossed and uncrossed conditions (not close enough for the crossed disparity and not far enough for the uncrossed disparity.) Given the average interpupillary distance and the test distance of 150cm it was found that the zero setting showed an inaccuracy of 0.004 MA from the theoretical. For the 12mm crossed disparity there was a 0.008 MA difference between the theoretical and the empirical, for the 9mm separation a 0.006 MA difference, and a 0.002 MA difference for the 6mm crossed disparity. For the 12mm uncrossed disparity the theoretical differed from the empirical by 0.003 MA, the 9mm by 0.001 MA, and finally the 6mm uncrossed differed by 0.006 MA. These
values are relative only to the average interpupillary distance in our study of 61.34mm (See Table 1). The MA differences above were also expressed in centimeters of difference (See Table 2). The zero setting, (no disparity), on the average, showed the perceived float was localized .99cm in front of the quoits ring, which corresponds to a 0.6% error between the theoretical and the empirical findings. The 12mm crossed theoretical differed from the empirical by 1.27cm (a 1.0% error), the 9mm crossed differed by 1.03cm (a 0.7% error) and the 6mm separation had a difference of .37cm (a 0.2% error). For the uncrossed disparities the 12mm theoretical differed from the empirical by 1.04cm (a 0.5% error) the 9mm separation by .30cm (a 0.1% error), and finally the 6mm uncrossed differed by 1.64cm (a 0.6% error) (See Table 1).

To see whether a statistically significant difference existed between the mathematically predicted "float" position (distance from the observer to the perceived ring) and the empirically measured distance, the average of the findings (in MA) for each person and for each disparity was compared to the theoretical float using a two-tailed t-test with 0.05 level of significance. A significant difference was found for each of the disparity conditions between the matched theoretical and empirical findings, with only the exception of the 6mm uncrossed disparity (0.481). Although statistically significant the actual difference in MAs was clinically insignificant.

When comparing the accuracy of stereolocalization between crossed and the uncrossed conditions (i.e. 12mm crossed to the 12mm uncrossed etc.) the 9mm and 12mm disparity conditions were significantly different while the 6mm condition showed no significant
difference. For two of the three disparity conditions, the 12mm and 9mm separations, the uncrossed responses were estimated closer to their theoretically derived distances than were the crossed disparity responses.
DISCUSSION

From our results it can be concluded that given a normal binocular system and under these specific conditions, subjects localized quite accurately for both disparity types, crossed and uncrossed, when compared to their respective mathematically calculated expecteds. Each of the seven averaged empirical responses to the disparities presented differed from their respective theoretical values by 1.0% or less. This indicates that the human binocular system is extremely accurate. There was an underestimation of the "float" under all disparity conditions of less than 1%, but this amount was slight and clinically was of little relevance. For example, if a quarterback were to throw a football 30yds, theoretically he would be within 1ft of the intended player given that he is using only binocular cues.

When comparing crossed against uncrossed disparity types, (using a paired two tailed t-test with a significance level of 0.05), only two settings, the 12 and 9mm uncrossed, were found to be significantly different from their corresponding opposite disparities. Again, although statistically significant, this error is small and clinically has little relevance. The underestimation found under each of the seven disparities may possibly be due to subtle mechanical errors within the apparatus, or to the inconsistencies associated with repeated measures.

This data provides a standard for stereolocalization performance. Since an approximate difference of 1% or less exists
between the theoretically determined response and the real, measured response, this can now be expected when testing the general population. In the future, this apparatus could also be used for the evaluation of progress in, and success of a given vision training program. This type of device could also be used as a teaching tool to help explain the concepts of stereolocalization and phenomena associated with it. Other uses include the evaluation of subjects for job environments which require excellent binocular depth perception (i.e. crane operation). The effects of lenses and prisms and the effect of artificially induced anisometropias and aniseikonias on stereolocalization can also be studied and should be.
BIBLIOGRAPHY


Getman G.N.: Polaroid rings as a skills test. Paper presented to 1948 conference on V.T., St. Louis MO.


Figure 2 Vectographic Principles
Trigonometric Method for Calculation of Theoretical Perceived Image Location

**Crossed Disparity (Base-Out)**

\[ \frac{PD}{(150 - X)} = \frac{X}{TS} \]

**Uncrossed Disparity (Base-In)**

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

Figure 9
FOR A MEAN PD OF 61.34 mm

<table>
<thead>
<tr>
<th>Setting</th>
<th>Theoretical (MA)</th>
<th>Standard Deviation (MA)</th>
<th>% Difference from Theoretical</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;0&quot; Setting</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Theoretical</td>
<td>0.6666</td>
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<td></td>
</tr>
<tr>
<td>Empirical</td>
<td>0.6706</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossed Disparities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12mm Crossed Theoretical</td>
<td>0.797</td>
<td>0.007</td>
<td>1.00</td>
</tr>
<tr>
<td>12mm Crossed Empirical</td>
<td>0.789</td>
<td>0.011</td>
<td></td>
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<tr>
<td>Theo/Emp Difference</td>
<td>0.008</td>
<td></td>
<td></td>
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<tr>
<td>9mm Crossed Theoretical</td>
<td>0.765</td>
<td>0.005</td>
<td>0.78</td>
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<tr>
<td>9mm Crossed Empirical</td>
<td>0.759</td>
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<tr>
<td>Theo/Emp Difference</td>
<td>0.006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6mm Crossed Theoretical</td>
<td>0.732</td>
<td>0.003</td>
<td>0.27</td>
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<tr>
<td>6mm Crossed Empirical</td>
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<td>0.045</td>
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</tr>
<tr>
<td>Theo/Emp Difference</td>
<td>0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncrossed Disparity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12mm Uncrossed Theoretical</td>
<td>0.536</td>
<td>0.007</td>
<td>0.56</td>
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<tr>
<td>12mm Uncrossed Empirical</td>
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<td>Theo/Emp Difference</td>
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<td></td>
</tr>
<tr>
<td>9mm Uncrossed Theoretical</td>
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<td>1.00</td>
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</tr>
<tr>
<td>Theo/Emp Difference</td>
<td>-0.006</td>
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<td></td>
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</tbody>
</table>

TABLE 1
### Average Theoretical Expecteds for Each Disparity

*For the average interpupillary distance of 61.34mm*

<table>
<thead>
<tr>
<th>Disparity Setting</th>
<th>Theoretical Distance in cm from Patient</th>
<th>Empirical Distance in cm from Patient</th>
<th>Theoretical Distance in MA from Patient</th>
<th>Empirical Distance in MA from Patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 MM Disparity</td>
<td>150.00</td>
<td>149.00</td>
<td>0.666</td>
<td>0.6706</td>
</tr>
<tr>
<td>12MM Crossed Disparity</td>
<td>125.47</td>
<td>126.74</td>
<td>0.797</td>
<td>0.789</td>
</tr>
<tr>
<td>9MM Crossed Disparity</td>
<td>130.71</td>
<td>131.75</td>
<td>0.765</td>
<td>0.759</td>
</tr>
<tr>
<td>6MM Crossed Disparity</td>
<td>136.66</td>
<td>136.98</td>
<td>0.732</td>
<td>0.73</td>
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<tr>
<td>12MM Uncrossed Disparity</td>
<td>186.56</td>
<td>185.52</td>
<td>0.536</td>
<td>0.539</td>
</tr>
<tr>
<td>9MM Uncrossed Disparity</td>
<td>175.74</td>
<td>175.43</td>
<td>0.569</td>
<td>0.57</td>
</tr>
<tr>
<td>6MM Uncrossed Disparity</td>
<td>166.38</td>
<td>164.74</td>
<td>0.601</td>
<td>0.607</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disparity Setting</th>
<th>Theoretical Distance in cm from Target</th>
<th>Empirical Distance in cm from Target</th>
<th>Theoretical Distance in MA from Target</th>
<th>Empirical Distance in MA from Patient</th>
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</thead>
<tbody>
<tr>
<td>0 MM Disparity</td>
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<td>1.00</td>
<td>0.00</td>
<td>0.0106</td>
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<td>12MM Crossed Disparity</td>
<td>24.53</td>
<td>23.26</td>
<td>0.137</td>
<td>0.129</td>
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<tr>
<td>9MM Crossed Disparity</td>
<td>19.29</td>
<td>18.25</td>
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<td>6MM Crossed Disparity</td>
<td>13.34</td>
<td>13.02</td>
<td>0.072</td>
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<td>0.124</td>
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<td>9MM Uncrossed Disparity</td>
<td>25.74</td>
<td>25.43</td>
<td>0.091</td>
<td>0.09</td>
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<tr>
<td>6MM Uncrossed Disparity</td>
<td>16.38</td>
<td>14.74</td>
<td>0.059</td>
<td>0.053</td>
</tr>
</tbody>
</table>

*MA (Meter Angles) = 1/meter i.e. 1/1.50m = 0.66 MA*