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The relationship of alignment hyperacuity to stereopsis

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Abstract

The term "alignment hyperacuity", a monocularly measured entity, is functionally described as the ability to detect an alignment of two points in space. It produces spatial thresholds usually 8 to 13 arc seconds of visual angle, which is smaller than those expected given the relatively large receptor density of the human retina. It has not been firmly established whether or not alignment hyperacuity performance is related to threshold stereopsis. This study examines the correlation between threshold stereoacuity and the sum of right and left eyes' monocular alignment detection hyperacuity measures.

Twenty-one subjects were evaluated measuring threshold stereoacuity with the Mentor BVAT II and monocular alignment hyperacuity with software designed at Pacific University College of Optometry. This study indicates that the sum of each eyes' alignment hyperacuity data should be equal to or slightly less sensitive (greater value) than an individual's threshold stereoacuity.

The lack of valid baseline knowledge about alignment detection hyperacuity and its relation to threshold stereopsis may be withholding optometric practitioners from understanding and/or testing certain aspects of alignment hyperacuity that might be of importance clinically including unexplained asthenopia, monitoring improvements in amblyopic therapy, and predicting potential stereoacuity in anti-strabismic treatment.

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THE RELATIONSHIP OF ALIGNMENT HYPERACUITY TO STEREOPSIS

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I attended North Dakota State University and then transferred to Pacific University to finish my Bachelor of Science in December of 1992. I am currently attending Pacific University College of Optometry and will be graduating in May of 1995. During my four years in optometry school, I have been envolved in various activities that focused on primary care optometry, contact lenses, and geriatric vision. My future plans include finding an associate position in a primary care practice in Minnesota or Wisconsin providing quality eye care, while acquiring skills and experience to become an excellent optometrist.

Amy Marie Fuhr

I attended South Dakota State University for 3 years before transferring to Pacific University to finish my undergraduate studies. I received a Bachelor of Science degree in 1992. I am currently enrolled at Pacific University in the optometric program with a planned graduation date of May 1995. While at Pacific University College of Optometry I have been involved in numerous activities, some of which include: being the Student Optometric president; being the student delegate at the American Optometric Association in 1993; assisting the disadvantaged in Cuzman, Mexico, and was chosen to Who's Who Among Students in Americans Universities. My future plans are to become an associate in a professional optometric practice providing quality care with specialized services in vision therapy, contact lenses, and low vision.

Abstract

The term "alignment hyperacuity", a monocularly measured entity, is functionally described as the ability to detect an alignment of two points in space. It produces spatial thresholds usually 8 to 13 arc seconds of visual angle, which is smaller than those expected given the relatively large receptor density of the human retina. It has not been firmly established whether or not alignment hyperacuity performance is related to threshold stereopsis. This study examines the correlation between threshold stereoacuity and the sum of right and left eyes' monocular alignment detection hyperacuity measures.

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Key words:
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Separation discrimination
Stereopsis
Threshold Stereoacuity

The Relationship of Alignment Hyperacuity to Stereopsis

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Introduction

The human visual system is very sensitive to changes in the position of objects in the visual field. Alignment hyperacuity, a monocularly measured entity, is functionally described as the ability to detect an alignment of two points in space. These displacement thresholds are usually 8 to 13 arc seconds of visual angle, smaller than the diameter of one foveal cone, and, therefore, are products of hyperacuity tasks.[1,2,3,4] Although subjects who are truly monocular may have hyperacuity as low as 3-8 arc seconds.[2] Other research has discovered that hyperacuity is not found to change with a function of age[5,6,7], is likely to be a consequence of a neural data processing by the visual system[8,9,10], performance improves with practice[11,12], and there are many types of hyperacuity, such as misalignment, vernier, and oscillating movement displacement threshold. [4,5,7,8,13,14,15,16,17]

Because alignment discrimination hyperacuity is an ability to detect an alignment within 8-13 arc seconds and the fovea intercone spacing is of a magnitude of 25 to 30 arc seconds, hyperacuity is assumed to be the product of processing beyond that available at the retinal level.[19] The signals that lead to hyperacuity are not present at the photoreceptor level and must, therefore, be the outcome of neural processing of visual information, presumably located in the visual cortex.[9] Paradiso et al. experimented with spatial discriminations and cortical processing and found that the ability to discriminate small differences in two visual patterns did not require that both patterns be presented at the same point in space.[8] They concluded from their study that visual stimuli available for comparison at higher visual processing levels and discrimination tasks involved cortical areas far beyond the striate cortex.

The visual system is also very resistant to noise produced by spatial jitter when performing a separation discrimination task, such as alignment hyperacuity.[1] McKee et al. found that the most precise foveal judgments require a visible reference target to determine between the oculomotor "jitter" and the target-driven changes in disparity.[15] A task called oscillatory movement displacement threshold (OMDT) is thought to involve some degree of motion processing.[5,20] Under optimal conditions, OMDT are typically 10 arc seconds, and, therefore, is classed as a hyperacuity. The detection of these oscillatory movements appears to be involved in the processing tasks of spatial localization. Whitaker et al. concluded in one experiment that the detection of movement and object displacement is also made easier by the presence of nearby stationary references, irrespective of the duration or type of movement.[21] Whitaker et al. also concluded from another experiment that at high contrasts there was no significant effect of line (target) length on hyperacuity displacement threshold but rather the gap between the reference points; and as the contrast decreased, the threshold increased.[7]

Additional hyperacuity studies have provided information about what targets provide the best stimulus and what stimulus causes a decrease in positional judgment. These studies show that hyperacuity improves as a function of contrast.[17] Stimuli that are of opposite-contrast result in poor hyperacuity threshold measurements than same-contrast stimuli.[22] Spatial position discrimination is much better for same than for opposite-contrast stimuli.[23] O'Shea et al. and Levi et al. reported that fine discriminations of spatial position of stimuli take place in the visual system where contrasts are treated independently, and, therefore, contrast polarity is a critical variable for spatial discrimination.[23,22] Separation discrimination can also differ under photopic and scotopic conditions. Under scotopic and photopic conditions, Yap et al. found that separation discrimination thresholds for widely separated targets are little changed from scotopic to photopic conditions. He also discovered that under scotopic conditions, discrimination thresholds were better and, therefore, cone input was not necessary for hyperacuity performance.[24]

Hyperacuity with relation to aging has been studied. Odom et al. found that vernier acuity, which is an example of hyperacuity, is little affected by minor optical changes that occur with age.[6] However, vernier bias, or accuracy, can be altered by diseases that affect the retina. Therefore, alignment tasks are a sensitive detector of some retinal pathologies. Whitaker et al. changed the method of the Odom et al. study and found that age has an affect on thresholds for vernier hyperacuities, depending upon the task requirements.[7] Their study found that no age-related trend was observed in vernier bias. It appears that vernier bias, or the difference between the subjective alignment and the true physical alignment, may vary and may be unpredictable. Lakshminarayanan et al. tested hyperacuity performance in various age groups ranging from 20 to 85 years. They found that vernier hyperacuity threshold was not found to vary with age.[18]

Alignment Hyperacuity and Threshold Stereopsis

Some basic visual science research has been done, little solid baseline data has been established regarding normative data of hyperacuity and testing condition designs. Additionally, the interrelationships of various hyperacuities has had minimal attention. The relationship of hyperacuity and stereoacuity represented as a function of threshold stereopsis has been previously found to have no direct relationship, but only minimal data was used to study this relationship.[15]

Stereoscopic tests require patients to detect a depth, or "z-axis" . Alignment hyperacuity, tested monocularly, represents the range of x or y plane displacement that will not be perceived as aligned by the patient. If this lateral "zone of insensitivity" to misalignment is applied combined binocular viewing conditions, the monocular ability to detect a spatial shift should need to be summed for a binocular perception of a spatial shift, or a binocular "zone of insensitivity" to positional change. Monocularly, these positional changes are perceived as lateral shifts, therefore, binocularly they should combine to yield a "z axis" shift or perception of a change in depth. This sum of "monocular zones of insensitivity to spatial shifts" should indicate the limit of the binocular threshold of a z-axis change, or threshold stereopsis. This hypothesis has been explored since the early 1900's. Around 1900, Stratton was the first to find a rough equivalence of the monocular sensitivity to displacement threshold and stereoacuity threshold.[25] He suggested that the factor limiting stereoacuity may be the monocular sensitivity for spatial displacement. This implies that stereoacuity thresholds are so similar in magnitude to hyperacuity thresholds that if stereoacuity were limited by monocular displacement sensitivity then the hyperacuity threshold should be one half the stereoacuity. Thus, the stereoacuity threshold would be defined as equal to the sum of the hyperacuity of each eye.

This lack of valid baseline knowledge about hyperacuity and its relation to threshold stereoacuity may be withholding optometric practitioners from understanding and/or testing certain aspects of hyperacuity that might be of importance clinically. For instance, testing hyperacuity may be useful for predicting potential stereoacuity after strabismus therapy, monitoring improvement in amblyopic therapy to determine when increased binocular rivalry may create binocular difficulties, and determining a possible reason for unexplained asthenopia.

This study is designed to record hyperacuity for each eye and threshold stereoacuity in a normal, adult population and determine if there is a correlation between hyperacuity and threshold stereoacuity. The study will use only easily accesable, affordable, and creatable software and hardware in which to keep the results constant in order to be repeated in a clinical setting.

Methods

Subjects:

Twenty-two students from Pacific University College of Optometry served as subjects for this experiment. Nine subjects were male and 13 subjects were female, ages 21 to 30 years old. All subjects had a comprehensive vision and ocular health examination within the last year. All had at least 20/20 visual acuity (OD, OS, and OU) through their habitual prescription. All had no history of amblyopia, strabismus, greater than 1/2 $^{\Delta}$ of vertical heterophoria, large lateral heterophoria (greater than 5 esophoric or 10 exophoric) or near point asthenopia. All subjects were free of ocular or systemic disease.

Pre-Testing Procedure:

All subjects performed two final screening entrance tests before proceeding with the stereopsis and hyperacuity testing. The two tests were distance visual acuity test using projected Snellen, and a distance Maddox Rod, performed both horizontally and vertically. Subjects were excluded from continuation of the experiment if visual acuity was not at least 20/20 or greater than 1/2 $^{\Delta}$ vertical phoria manifested.

Experimental Procedure

Threshold Stereopsis

Threshold stereopsis was tested by modifying standard testing procedures with the Mentor BVAT II Visual Acuity Tester. Normal room illumination was used, and the subject sat in a chair, which set the subject at the same eye level with the BVAT. Since the incremental changes of the stereoptic targets provided by the BVAT are large considering the goal of a threshold measurement, the BVAT was set for 15 arc seconds at a testing distance of three meters. Subjects were moved from a non-detection to detection position (far to near), where they could correctly identify the disparate target on the BVAT II screen (see Figure 1). Once the subject correctly identified the disparate image from five to eight times at a given distance, the distance from the monitor to the subject was measured to the nearest centimeter. This measured distance, when compared to the calibrated distance of the BVAT II, allowed simple calculation of the subject's threshold stereopsis. This formula is as follows:

$$T=(3.0/D)\times 15$$

Key: **T=** threshold stereoacuity calculated for subject (arc seconds)
3.0= calibrated testing distance for BVAT (meters)
D= distance from the monitor to the subject (meters)
15= disparity of the stereoacuity target (arc seconds)

Hyperacuity

The stimuli were displayed on a 13" Apple color high resolution RGB monitor. The computer was aligned side by side with the Mentor BVAT. Software to test alignment hyperacuity was used which was developed at Pacific University College of Optometry and is currently not available commercially. The same testing conditions used previously for the threshold stereoacuity testing were used for hyperacuity testing. Using the same distance as the threshold stereoacuity measured for each subject, the subject was instructed to sit in a chair in front of the Macintosh LCII computer screen, a computer mouse was placed on a table in front of the subject, and one of the subject's eyes were patched.

Figure 1.

Mentor BVAT II Stereo Screen Display

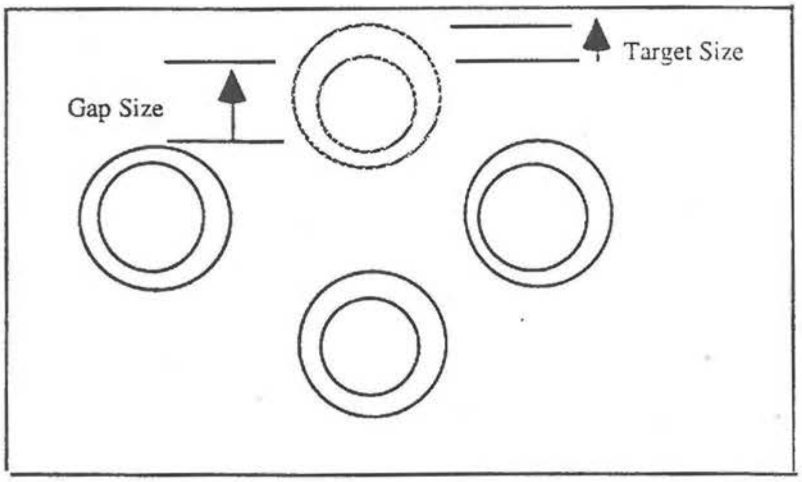
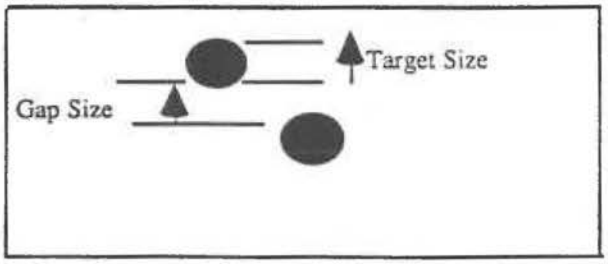


Figure 2 .

Macintosh Computer Screen Hyperacuity Display



The screen displayed two dots, the bottom dot was held constant and served as a reference, while the top dot was presented at random either to the left or to the right of the bottom dot for each trial. The subject moved the mouse accordingly to align the two dots vertically. When aligned, the subject clicked the mouse to enter the data. This data was stored as arc seconds of displacement for perfect alignment for each measurement. Since the incremental changes are limited by angular subtense of pixel size (hence, also affected by testing distance), the minimal increments of change were 37.41 arc seconds for the three meters. The exact value changed depending on the individuals subject's testing distance. One hundred fifty measures were taken to allow calculation of each eye's hyperacuity. Data were collected in 6 sets of 25 trials, such that stimuli were presented 150 times per eye. A short break occurred between each set of 25 trials. These trials allow consistent calculation of this "zone of insensitivity" to alignment with a 99 % confidence interval.

The stimulus pattern provided two variables (see Figure 2). The circle width provided the target size of each "dot". The void provided the gap between the reference and variable circles provided by the "gap" size. The stimuli were adjusted for each testing distance to keep equivalent angle subtense consistent for both distances (see Figures 1 and 2).

Since the hyperacuity program operates on the basis of angular subtense, these values needed to be calculated for each subjects threshold stereopsis distance to keep the program calibrated. The computer program produced two vertically oriented dots, equal in gap size and target size to the Mentor BVAT II circles for each subject's threshold stereopsis testing distance. This kept testing conditions virtually identical for each set of measures.

By keeping the targets of interest at the same retinal image size from one condition to the second condition, we attempted to eliminate a critical variable sometimes not accounted for in this type of research. However, by asking the subject to perform misalignment judging task with such a gap size, the portion of the retina processing the alignment cues compared to that used to detect stereopsis was much larger. Therefore, we ultimitely overcompensated, setting up the test to yield higher hyperacuity values than the hypothesis predicts.

The gap size of the Mentor BVAT II circles was measured as 0.01 m and the target size was measured as 0.003 m at a testing distance of 3.0 m. To calculate the computer gap size and target size at the subject's threshold stereoacuity distance, the following formulas were used:

To calculate gap size in arc seconds:

Gap size=[(tan of 0.01/D)x3600

Key: tan= Tangent
D= Threshold stereoacuity distance (meters)
0.01= Gap size of the BVAT target when calibrated for 3.0 meters and 15 arc seconds (meters)
3600= Conversion of degrees to arc seconds

To calculate target size in arc seconds:

Target size= (tan of 0.003/D)x3600

Key: tan= Tangent angle
D= Threshold stereoacuity distance (meters)
0.003= Target size of the BVAT set at 3.0 meters and15 arc seconds (meters)
3600= Conversion of degrees to arc seconds

At the fovea, Panum's fusional area representation for each eye is around 5 arc seconds.[26] This value grows rapidly as distance from the fovea increases. Given the angular subtense of our targets, it was determined that any alignment data points over +/- 300 arc seconds were erroneous and were discarded. Out of 6300 total data points, only 15 exceeded the 300 arc second value, in which the subject accidentally clicked the mouse before alignment. Of the 22 subjects tested, one subject's result was not included. The subject did not follow the instruction set completely throughout the testing.

Results

Figure 3 shows the results from the 21 subjects. The central point for each subject represents the "habitual skew" of alignment hyperacuity from the 150 trials run on each eye. The distribution line represents the hyperacuity (plus and minus) around this central point. These were calculated using a 99% confidence interval. The 99% confidence interval demonstrates the range of values for which the subject could not detect misalignment of the two targets, thus, this range (plus and minus values) is defined as "alignment hyperacuity" for each eye. The hyperacuity value is one half of this range. Sequential hash marks on the x axis represent each subjects right and left eyes' findings.

Figure 3.

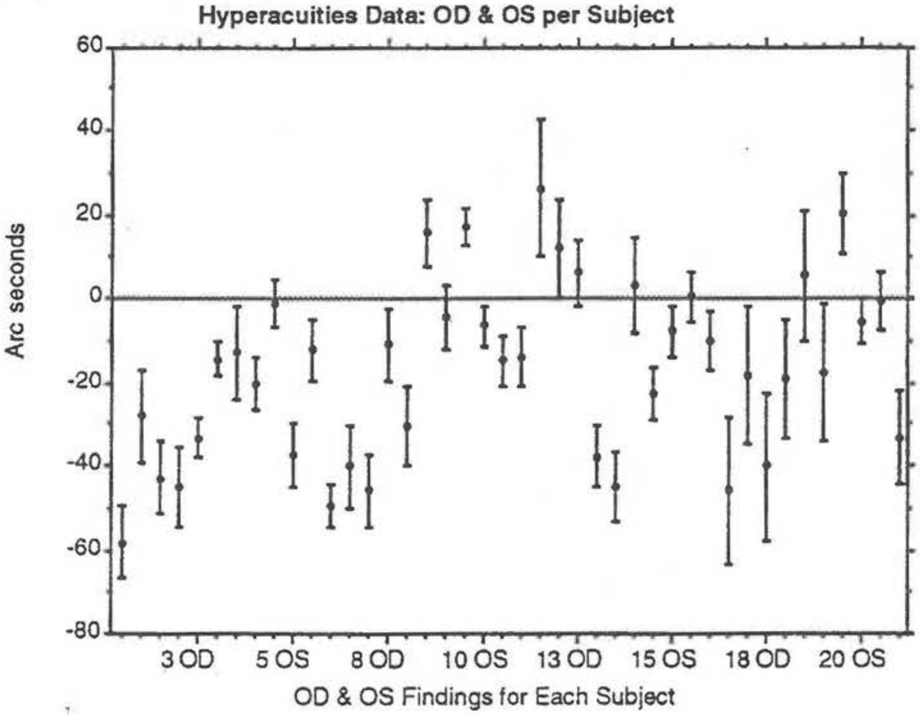
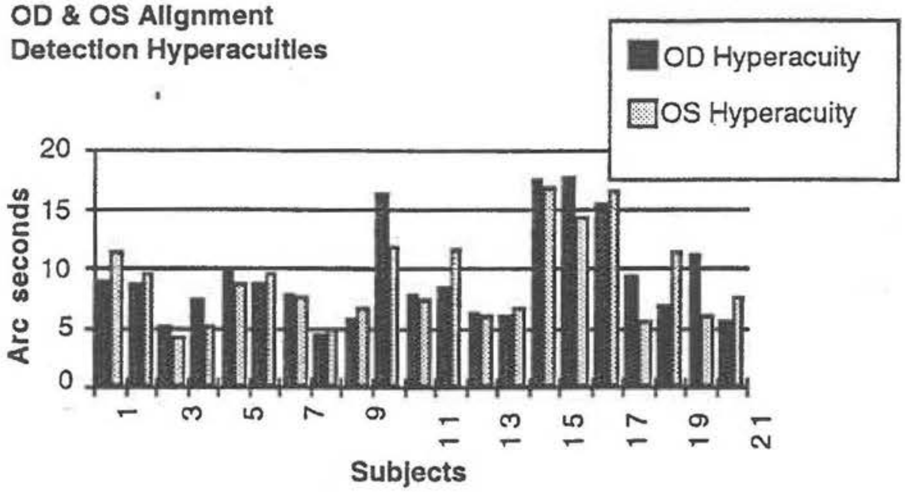


Figure 4 shows the individual right and left eyes' alignment hyperacuity for each of the 21 subjects. Fifteen of our patients (71.4%) had equal to or less than 2 arc seconds difference between right and left eye measurements.

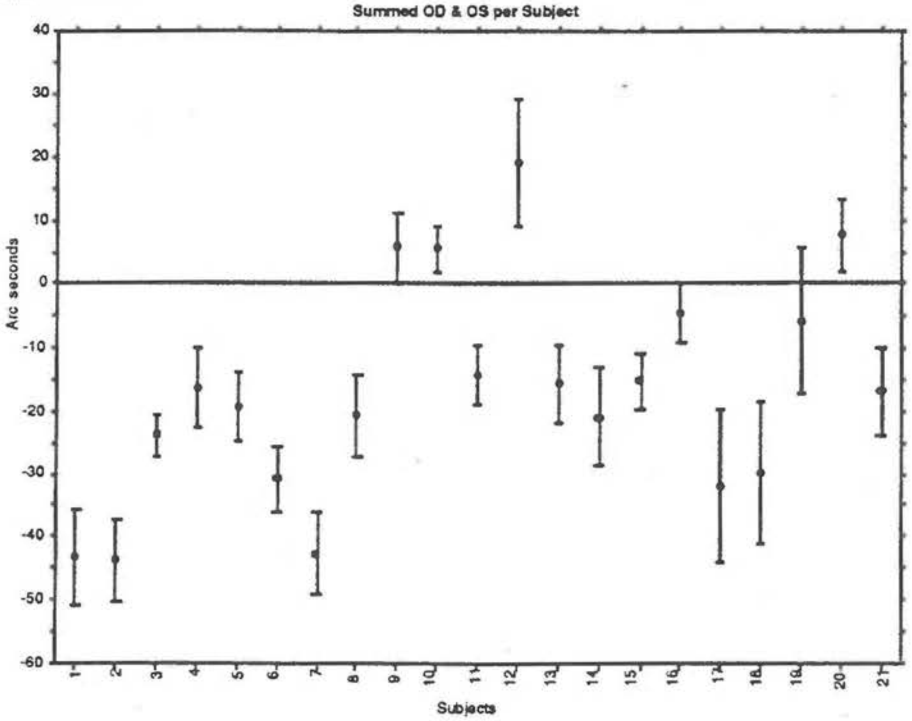
Figure 4.



OD & OS Alignment Detection Hyperacuities

Figure 5 is a continuation of Figure 3 and 4. It shows the 21 subjects' summed hyperacuity from the right and left eye results. A 99% confidence interval illustrates the findings. This below value for each subject, is the misalignment "total" which will be compared to threshold stereopsis values.

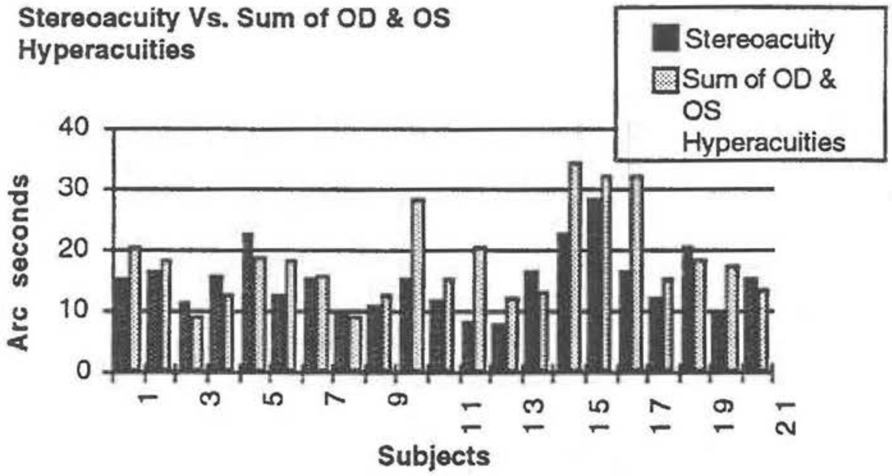
Figure 5.



Summed OD & OS per Subject

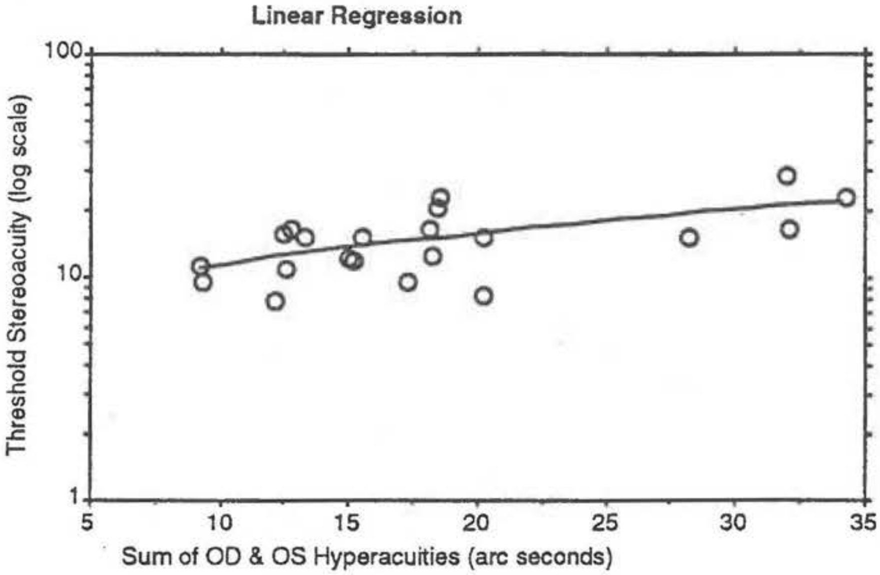
Figure 6 shows a comparison of the threshold stereopsis values to the sum of the OD and OS alignment detection hyperacuities for each subject. The mean sum of hyperacuities was 18.32 arc seconds with a standard deviation of 7.37. The mean threshold stereoacuity was 14.85 arc seconds with a standard deviation of 5.15. Fourteen of the twenty-one subjects (66.67%) had summed hyperacuities that were equal to or slightly less sensitive (a greater value) than the threshold stereoacuity. The seven subjects that displayed higher threshold stereoacuity than summed hyperacuity were within one standard deviation of error, therefore these differences from the predicted tendencies are negligible.

Figure 6.



Two types of analyses were performed on the relationship between summed hyperacuity and threshold stereoacuity. The first was a one factor ANOVA. Our findings were significant (p=.0126), thus supporting our hypothesis that an individual's threshold stereoacuity should be equal to or slightly greater than the sum of the monocular hyperacuities. The second analysis was a linear regression (Figure 7) with an R value of .623 indicating a significant correlation.

Figure 7.



All the above results show a direct relationship between the sum of monocular alignment hyperacuities and threshold stereoacuity.

Discussion

The present data clearly show that there is a significant correlation between threshold stereoacuity and the sum of monocular misalignment hyperacuities. Our results indicate that even though we measured the threshold stereoacuity and compared it to the sum of the comparatively insensitive misalignment detection hyperacuity findings, there was still a significant correlation. Our results were seemingly different from previously published research in this area by McKee et al.[15] However, their experimental design was different, the subject pool was much smaller. They investigated the relationship between stereoacuity judgments to several other positional judgments, rather than the direct correlation test presented here.

Our study shows that threshold stereoacuity appears to be related to the sum of monocular alignment hyperacuities, which makes this type of hyperacuity testing an important component of clinical assessment of vision. It should be possible to measure the performance of subjects on hyperacuity tasks and then make a comparison to performance on stereoacuity tasks. If stereopsis is comparatively deficient, it may be possible to measure OD and OS hyperacuities to predict potential stereopsis after therapy. Additionally, if, with improvement of amblyopia, hyperacuity of the poorer eye rapidly improves, this should in turn allow an increase in stereopsis. The comparison of these values may give valuable insight into the degree of perceptual improvement and potentially be an index of increased stress on binocularity as monocular skills improve.

Hyperacuity and its relation to visual deprivation and amblyopia have been researched. For instance, cats appear to possess vernier acuity that is considered to be a true hyperacuity. Monocular deprivation in cats causes loss of vernier acuity that may indicate that animal models may be useful for assessment of the abnormalities present in the amblyopic human visual system.[2] Another previously discussed type of hyperacuity, OMDT, is reduced in amblyopia for all temporal frequencies, thus showing that both magnocellular and parvocellular channels in the lateral geniculate nucleus are affected by amblyopia.[28] Different types of amblyopia have been compared with hyperacuity and discovered that strabismic amblyopes show more of a loss to hyperacuity than anisometropic amblyopes.[13,17] Further studies should reveal if 1) hyperacuity increases in sensitivity with therapy 2) hyperacuity is an index or significant factor in binocular stress.

Administration of this test takes about 25 minutes to collect all data. Its simplicity lends its way its way to allow support staff to easily perform this test on a patient in a private practice setting. It's value maybe great, depending on the type of case, practice emphasis, and results of future research.

To summarize, our results show that an individual that has a normal binocular visual system should have a threshold stereoacuity equal to or slightly more sensitive (smaller value) than the sum of their monocular alignment detection hyperacuities. Future studies will try to find an even closer relationship using more central targets and compare hyperacuity with other binocular measures.

Conclusion

The subject's threshold stereoacuity was measured with the BVAT II. The disparate circles are, of course, were made up from an infinite number of black dots. When determining the angular subtense to use for the hyperacuity task, the farthest points on the BVAT circle (most superior and most inferior) were used instead of measuring closer points. This means that this project measured the most sensitive threshold stereoacuity and the least sensitive monocular hyperacuity. This essentially set up the least likely conditions to allow a validation of the hypothesis.

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