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Abstract

Hyperacuity describes a variety of visual functions which are measured at thresholds smaller than expected given comparatively large receptor spacing and the subsequent predicted retinal image quality of the human eye. Monocular alignment hyperacuity is the ability to make very fine judgments of lateral or vertical displacement. There are numerous clinical uses for monocular alignment hyperacuity; however, there exists little procedural continuity among research in this area. This lack of continuity makes clinical adaptation and interpretation difficult. This project attempts to establish an efficient protocol for the measurement of monocular alignment hyperacuity in order to increase its clinical applicability and interpretability. Nineteen subjects each performed 300 trials at two testing distances using the method of subjective adjustment to alignment. The distribution of errors from alignment allow calculation of monocular alignment hyperacuity. Results indicate that a useful and consistent monocular alignment hyperacuity can be obtained in 250 trials on any cooperative subject or patient. Methods are suggested to decrease the number of trials necessary for clinical efficiency. Additionally, even though the angular subtense of the test stimuli were kept constant at one meter and six meters, the six meters testing distance yields lower thresholds (greater sensitivity) than that of the one meter distance, possibly due to increased peripheral cues to alignment.

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A CLINICAL PROTOCOL FOR THE DETERMINATION OF MONOCULAR ALIGNMENT HYPERACUITY

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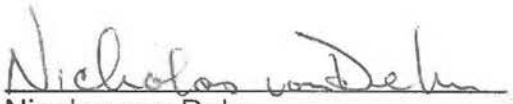

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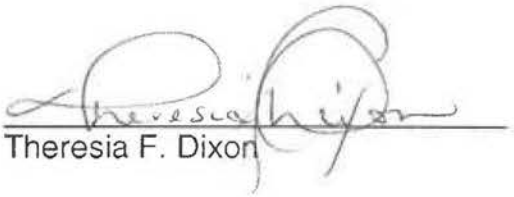

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Seema Kamal graduated with a Bachelor of Science Degree in Cellular, Molecular, and Microbial Biology from The University of Calgary, in Alberta, Canada. She is presently attending Pacific University College of Optometry and will graduate in May of 1995. Her immediate future plans are to practice primary care optometry in the Northwestern United States or Western Canada. She hopes to continue her association with Amigos in providing vision care to the underprivileged in North America and around the world.

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ABSTRACT

Hyperacuity describes a variety of visual functions which are measured at thresholds smaller than expected given comparatively large receptor spacing and the subsequent predicted retinal image quality of the human eye. Monocular alignment hyperacuity is the ability to make very fine judgments of lateral or vertical displacement. There are numerous clinical uses for monocular alignment hyperacuity; however, there exists little procedural continuity among research in this area. This lack of continuity makes clinical adaptation and interpretation difficult. This project attempts to establish an efficient protocol for the measurement of monocular alignment hyperacuity in order to increase its clinical applicability and interpretability. Nineteen subjects each performed 300 trials at two testing distances using the method of subjective adjustment to alignment. The distribution of errors from alignment allow calculation of monocular alignment hyperacuity. Results indicate that a useful and consistent monocular alignment hyperacuity can be obtained in 250 trials on any cooperative subject or patient. Methods are suggested to decrease the number of trials necessary for clinical efficiency. Additionally, even though the angular subtense of the test stimuli were kept constant at one meter and six meters, the six meters testing distance yields lower thresholds (greater sensitivity) than that of the one meter distance, possibly due to increased peripheral cues to alignment.

INTRODUCTION

Hyperacuity is defined as the ability to perceive a difference in relative spatial localization of two or more visual stimuli. The human visual system has the ability to make displacement or alignment judgments to a much finer degree than would be predicted by the spacing of elements of the retinal mosaic. The term "hyperacuity" was coined by Gerald Westheimer to distinguish this ability from that of visual resolution, or

"visual acuity".[1] Visual resolution refers to the ability to perceive individual objects as being separate or resolvable, whereas monocular alignment hyperacuity is the ability to perceive where one object is relative to another object in space. The hyperacuity that this study explores can be described as monocular alignment sensitivity or monocular alignment hyperacuity. Alignment hyperacuity defines the range of target displacement in which alignment is perceived. This implies that the barely detectable displacement of the target which is perceived as displaced by the subject, lies just beyond the alignment range.

The development of monocular alignment hyperacuity ability throughout life is described elsewhere.[2] Typical adult values are measured on the order of 3 -13 seconds of arc, depending upon target parameters and subject experience.[3,4,5] Details of the retinal mosaic, however, only predict sensitivity to minutes of arc. It is generally agreed, therefore, that any hyperacuity judgments must be the product of a higher level cortical process.

Monocular alignment hyperacuity is resistant to optical degradation of up to one or two diopters of defocus.[5] This finding is explained by a "center of gravity" analogy, in which the arithmetic mean, or centroid, of the light distribution is evaluated and attributed to the whole, such that the center of a point of light still registers at the same point.[8] Because of this resistance to degradation, hyperacuity measurements have been proposed as a method of evaluating retinal patency as an indicator for predicting potential acuity after cataract removal.[9] Similarly, "hyperacuity perimetry" can be used to locate and evaluate areas of visual disturbance while minimizing the effects of media opacities.[5] Another clinical use that is suggested is for quantifying metamorphopsia due to retinal and preretinal anomalies and disease (CME). Monocular alignment hyperacuity measurements can be used for following a disease process and evaluating

the efficacy of treatment. Lakshminarayanan, et al, describe a Modified Amsler Grid, based on the fact that the Amsler grid is actually a bisection hyperacuity task which finely delineates areas of metamorphopsia with macular edema.[3]

Several types of testing paradigms have been described, including vernier alignment (line vernier and two-dot vernier), bisection tasks, orientation discrimination, and displacement threshold (the detection of change in position over time).[3,5] Threshold values for all of these drop much more sharply than visual acuity with increasing distance from the fovea; and at any given retinal location, the lowest thresholds are similar for all types of hyperacuity tasks.[1,6,7]

Different psychophysical methods are used to present the experiment stimuli to the subject. Early studies employed a 2-alternative forced choice staircase (FCS), in which the subject makes a definite judgment about the offset of a discreet stimulus presentation before continuing with the test. Based on the accuracy of this judgment, the computer presents the new trial in an ascending or descending level of offset difficulty.[9] More recent experiments use the method of adjustment (MOA), which is typically just as accurate and much faster than the FCS. Reich, et al. find that results obtained in 3 minutes using the MOA are comparable to those which require greater than 30 minutes using the FCS.[9] With the MOA, the subject actively participates by controlling the changes in the stimulus to provide the chosen response.

For measuring monocular alignment hyperacuity, some studies use light-emitting diodes as targets, mounted on tracks perpendicular to semi-silvered mirrors, although most studies present the targets on a computer screen and the subject is asked to move a "mouse" or joystick to bring the targets into alignment.[10]

There are many methods of determining monocular misalignment hyperacuity, most of which are either clinically unaffordable or impractical, or have poorly described methods. Another difficulty at the clinical level is that since a computer monitor is typically used, the finest disparity shown to the patient is limited by pixel density. Even at six meters, most monitors only allow 12.47 seconds of arc as the minimum increment of adjustment. Therefore a direct monocular alignment measurement cannot be made, but instead must be calculated through taking repeated trials and then statistically deriving hyperacuity based on the distribution of the subject's responses. The number of measurements taken varies with the psychophysical method used, the method of target presentation, the type of hyperacuity being measured, and the goal of the researchers. Past studies used from eight trials to as many as 10,000 trials.[4] In developing a clinically useful test, the minimum number of measurements needed for an accurate result must be determined.

Hyperacuity thresholds are calculated from the distribution of several subjective responses. The more tightly grouped the responses are, the lower the threshold is (greater sensitivity to alignment). The term "bias" refers to the mean of the leftward and rightward responses (assuming vertically oriented targets), that is, the constant or mean error in the subject's responses. This indicates a subjective "skew" to the subject's perception of alignment. The monocular alignment hyperacuity is represented by the distribution of responses around this habitual "skew" point. The results are greatly dependent upon the vertical gap between the two objects presented. In general, the larger the gap size, the further the targets are from the fovea, the higher the threshold (i.e., the poorer the performance).

A learning curve is seen in hyperacuity testing. Fahle and Edelman show an initially steep decline in thresholds for monocular alignment hyperacuity.[4] After this first phase,

learning continues relatively monotonically even after 10,000 trials. Informally, the researchers notice slight improvements after several months of practice. It is interesting to note, however, that learning is specific for a given orientation of stimulus. For a stimulus rotated 90° from the original learned orientation, the researchers find thresholds higher than that for completely inexperienced subjects. In another study, by Osuobeni, it is shown that monocularly blind subjects demonstrate better monocular alignment hyperacuity than amblyopic subjects, who in turn perform better than normal binocular subjects.[10] The explanation given is that the monocularly blind subjects are more experienced in making monocular visual judgments. Indeed, further research shows no significant difference between mean monocular alignment hyperacuities for monocularly blind subjects and a control group experienced in making monocular alignment judgments, thus indicating the cortical nature of this measurement.[10]

Previous studies demonstrate little procedural continuity among researchers. Enoch and Williams provide an excellent discussion of the procedures and problems encountered in bringing a psychophysical test to a clinical environment.[11] They state that psychophysical tests have an advantage in clinical testing in that information about the patient is gathered in a noninvasive manner. They suggest that parameters should be selected that are relatively insensitive to variables encountered in the field (clinic) in a normal population, but which are sensitive to changes in the response system being studied.[11] This project is designed to establish an efficient and inexpensive protocol for the measurement of monocular alignment hyperacuity in order to allow its clinical application. The goals of the present study are threefold: to establish the validity of this protocol, to establish the minimum number of trials necessary for a useful monocular alignment hyperacuity value, and to determine if a change in testing distance will result in different monocular alignment hyperacuity threshold measurements.

METHODS

Nineteen optometry students, ages 20-29, were chosen as subjects. Each subject had best corrected monocular visual acuities of 20/20 or better and no history of strabismus, amblyopia, or a general binocular dysfunction. Although visual acuity is not considered a crucial factor, as monocular alignment hyperacuity is relatively resistant to image degradation, the purpose of this visual acuity screening was to specifically exclude amblyopes, who are noted to perform better with their preferred eye than normal binocular subjects on such monocular alignment tasks.[2]

The program software for testing monocular alignment hyperacuity in the current study was developed at Pacific University College of Optometry. Trials for all subjects were performed at two distances, one meter and six meters. The stimulus pattern consisted of two vertically oriented dots with a diameter of 4.990 arc minutes at one meter and 4.782 arc minutes at six meters, separated by a gap of 38.671 arc minutes at one meter and 38.463 arc minutes at six meters. The target diameter and gap size were chosen to maintain a constant angular subtense between the two distances, thereby presenting the same testing conditions to the same perifoveal area. The stimuli were displayed on a 13 inch Apple Color High-Resolution RGB monitor. An Apple Macintosh computer controlled the display, data collection, and analysis. Overhead fluorescent lights provided moderate room illumination and the screen was positioned to minimize any reflections. Previous experiments have shown that spot luminance does not significantly influence the results of such hyperacuity tasks.[4]

Testing was performed monocularly, with each subject wearing a patch over the nonpreferred eye. Subjects were randomly assigned to start with either the one meter or the six meters distance. Three hundred trials were performed at each testing

distance, and the data were saved after each 25-trial interval. The method of adjustment was used to determine thresholds. Subjects were asked to determine whether the upper dot was to the left or right of the lower dot, and then to use a "mouse" to laterally move the upper dot (Fig. 1). When the subject determined that the dots were vertically aligned, this decision was signaled by clicking the mouse. After each trial, the upper dot was programmed to move to a randomly offset location before the next trial.

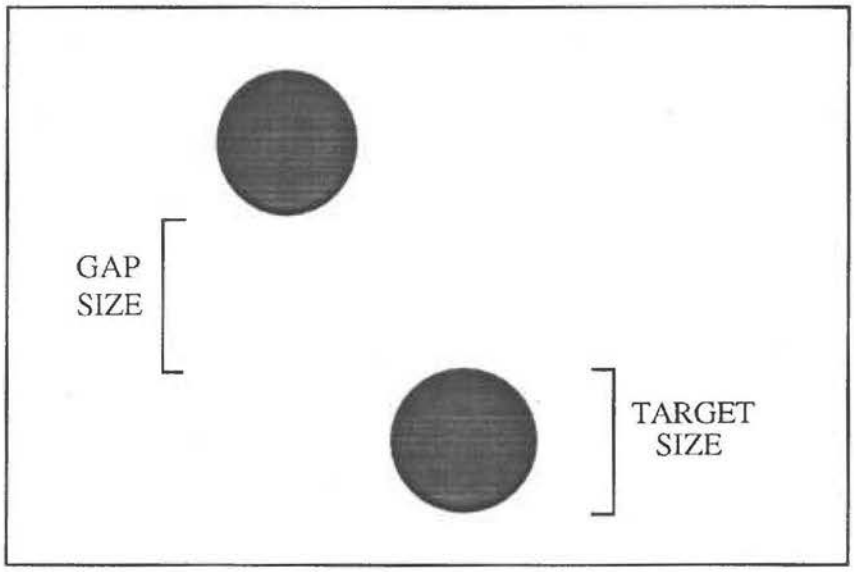


Figure 1: Stimulus configuration used in the 2 dot alignment test

A total of 19 subjects were tested at one meter and six meters. A total of 300 trials per subject at each distance was taken with a new monocular alignment hyperacuity value being generated at every consecutive 25 trial interval. The monocular alignment hyperacuity value is defined as half of the 99% confidence interval of all data collected up to that point (alignment sensitivity each side of the mean).

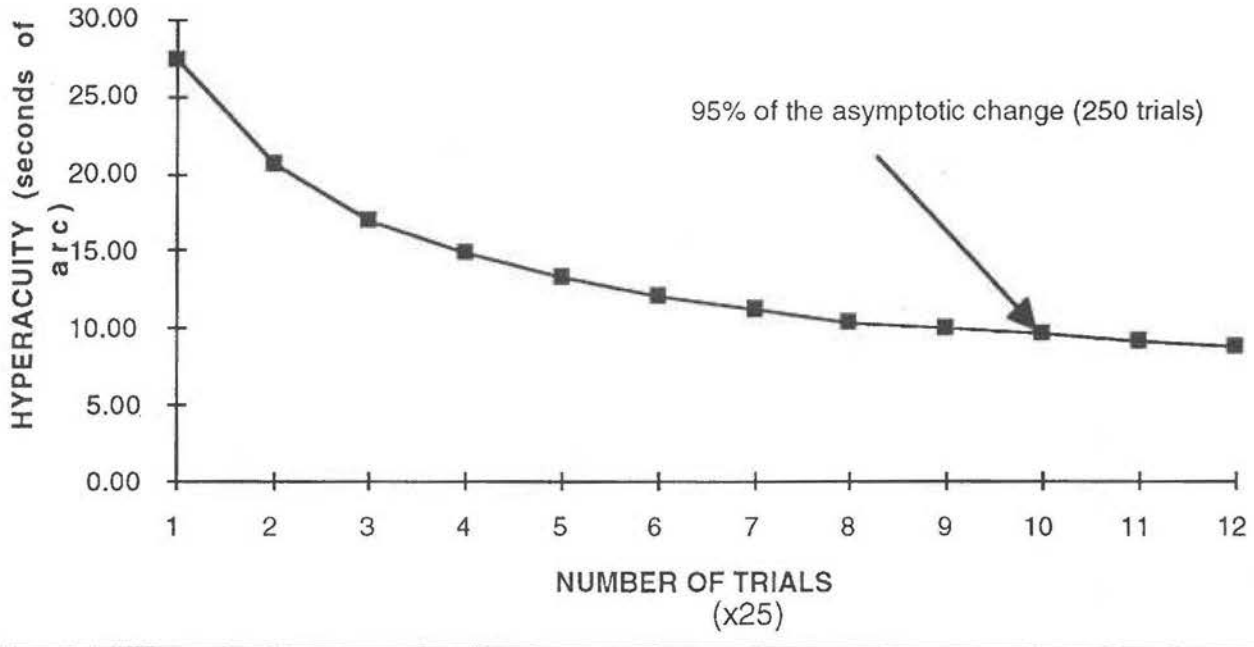
There are several ways to statistically derive the "true" monocular alignment hyperacuity value: as a time function of an asymptote, on an individual basis once less than a 5%

change occurs with consecutive intervals of testing, or when 95% of the asymptotic change is reached. For clinical usefulness, the point which allows 95% of the increase in sensitivity to occur, should be an adequate number of trials to provide a good endpoint. Limitations of this method are considered in the discussion.

RESULTS

A total of 19 eyes of 19 subjects ranging between the ages of 20 and 28 years were tested at one and six meters. Monocular alignment hyperacuity versus number of trials performed was plotted for each subject. These curves were averaged to produce figures 2 and 3. The curves follow an initial steep decline which level off with further testing. This indicates that for each subject, the monocular alignment hyperacuity measurement after 300 trials as compared to the value after 25 trials demonstrated an improved accuracy as a result of increased patient experience and an increase in the database for the calculation of the confidence interval. Both graphs show that to achieve 95% of the asymptotic change, 250 trials are needed.

Figure 3. Average Monocular Alignment Hyperacuity at 6M Over 300 Trials



A comparison of the one and six meter curves reveals that the monocular alignment hyperacuity at six meters is consistently lower (more sensitive) than at one meter (Fig 4). A two-tailed *t*- test was performed on the individual monocular alignment hyperacuity scores attained at the 250 trial point. A significant mean difference of 2.7 seconds of arc ($p = 0.0001$) was found between the two distances (Table 1).

Figure 4. Compared Average Monocular Alignment Hyperacuity For 1M and 6M

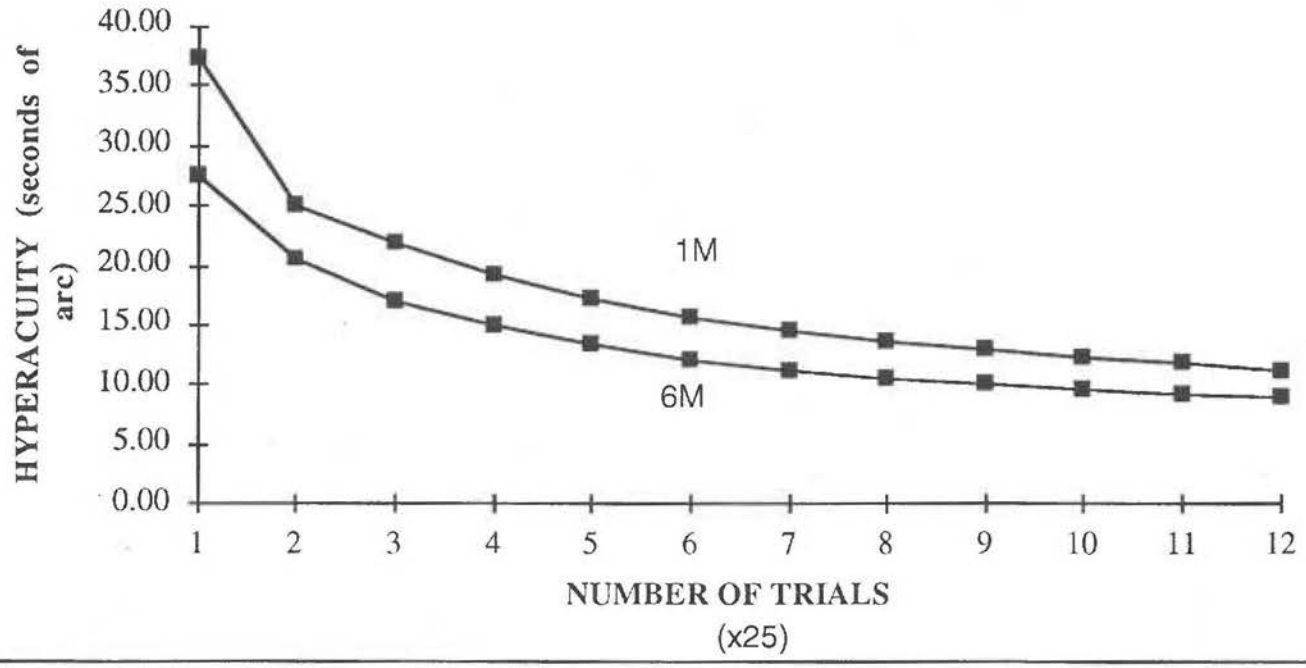


Table 1: One and Six Meters Monocular Alignment Hyperacuity at 250 Trials for Each Subject

SUBJECT	1M HYPER AT 250 trials (arc sec)	6M HYPER AT 250 trials (arc sec)
1	16.04	8.80
2	10.28	8.54
3	14.49	11.92
4	10.34	9.01
5	11.31	8.79
6	8.23	7.14
7	9.80	5.92
8	17.05	13.38
9	10.55	11.51
10	16.16	14.02
11	12.95	7.89
12	13.41	12.12
13	11.55	8.07
14	12.17	7.69
15	12.93	10.64
16	12.50	12.25
17	13.28	9.36
18	13.03	9.29
19	9.53	7.97

DISCUSSION

The results indicate that the number of trials necessary to obtain a consistent value of monocular alignment hyperacuity with our experimental parameters is 250 for both one meter and six meters testing distances. This is the point at which 95% of the asymptotic change is achieved. Two hundred fifty trials is higher than we had expected, based on previous research. For instance, Enoch and Williams noted that 10-20 trials generally give a reliable estimate of threshold, but this seems to have been an informal observation and different testing conditions applied.[11] One reason for this higher than expected number may be that a 99% confidence interval was used to calculate monocular alignment hyperacuity values. The selected 99% confidence level used in this experiment may be more stringent than would be necessary in a clinical setting, but offers a greater assurance of the calculated value.

The clinical applicability is further limited by the length of time required for testing. On average, our subjects needed approximately 70 minutes to complete the entire procedure of 600 trials (300 trials with one eye at each distance). With 250 trials per eye, an average testing time of 58 minutes would be necessary to obtain data on both eyes at one distance. A 75% confidence level may decrease the procedure time, thus making hyperacuity testing more clinically efficient, but likely less reliable.

The length of time necessary for testing led us to expect that subject fatigue might increase the variability of responses as testing progressed. This appears not to be the case, as the variance, and hence the standard deviation, conforms to the number of trials performed. Learning seems to be a more important factor in accuracy of alignment than subject fatigue. This finding supports performing a higher than

anticipated number of trials, and perhaps providing a 25 trial "practice" before starting data collection.

There is initially a dramatic decline in monocular alignment hyperacuity values, which is followed by a much more gradual improvement in performance that persists throughout the experimental sequence. We would expect this progression to continue past 300 trials; however, we make the assumption that this asymptotic improvement would not occur at a rate which would alter clinical data gathering methods. The general progression of each subject's monocular alignment hyperacuity curve is similar. This brings up the interesting possibility of creating a data analysis program that would create a curve extrapolated from relatively fewer trials to calculate a reliable estimate of monocular alignment hyperacuity threshold.

A change in the testing distance from one meter to six meters appears not to affect the overall slope of the curves, demonstrating that learning has the same effect regardless of distance. This indicates that testing distance is not a critical factor as long as the chosen distance is specified. Our data show that the six meters monocular alignment hyperacuity values are consistently more sensitive measures than the one meter values (Table 1). We suspect that this improved performance at a greater testing distance is the result of increased peripheral cues to alignment.

It is clinically feasible to perform 250 trials but there may be those individuals who reach a reliable endpoint with a lower number of trials and those who perhaps would require more trials; though likely not many more. For consistency and clinical accuracy, 250 trials will allow the clinician to interpret and compare data to other research and monitor changes over a period of time.

A possible limitation to this experiment is that only young subjects were used. However, Lakshminarayanan, et al. have shown that age seems not to affect monocular alignment hyperacuity threshold judgments.[12] The possibility of head movement or tilt was not controlled. Some previous researchers have used a chin rest to control this variable. However, barring extreme postural shifts during the test administration, we do not feel that this is a significant confounding factor.

In conclusion, we have presented a protocol for the clinical measurement of monocular alignment hyperacuity. From this, we determined that 250 trials are necessary for a valid monocular alignment hyperacuity measurement. We feel that although 250 trials would be too time consuming for frequent clinical use, software could possibly be developed that would arrive at a comparable value through extrapolation from a fewer number of trials. The one meter and six meters testing distances show similar trends, with the six meters values consistently showing greater sensitivity to alignment, possibly due to more peripheral alignment cues in the visual field as the subject's testing distance increases from the computer monitor.

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