Stereoscopic acuity and observation distance

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Because of the contradictory evidence as to whether stereoscopic acuity varies with observation distance, this study was undertaken to investigate the problem, with the utmost care being taken to maintain constant experimental conditions and to eliminate empirical clues to depth perception. By means of a haploscopic apparatus, which allowed careful control of all parameters, the stereoscopic acuity of three subjects with full accommodation was determined in prolonged experiments for seven observation distances from 6 M. to 40 cm. Standard psychophysical methods were used. The results indicated that stereoscopic acuity remains essentially constant, at least for observation distances beyond 50 cm. For one subject there was no change in stereoscopic acuity in distances from 6 M. to 40 cm. Two subjects showed essentially no change from 6 M. to 50 cm., but they did show a small decrease at the test distance of 40 cm. It was found also that controlling pupil size was unnecessary with a constant level of adapting luminance of about 50 millilamberts.

A problem not satisfactorily resolved is concerned with whether stereoscopic acuity changes with a change in viewing distance of the test details. This problem probably is related in one way or another to whether visual acuity changes with observation distance. Somewhat contradictory evidence has been reported in the literature, although Sloan,[1] in her review of the literature in 1951, was of the opinion that under adequately controlled conditions visual acuity was practically independent of fixation distance for distances beyond 2 M., whereas for distances less than 1 M. she believed that the evidence indicated some decrease in visual acuity with decreased distance. Such reported changes are always difficult to evaluate and, of course, various possibilities have been suggested to account for a decreased acuity at near distance; such possibilities can include inadequate accommodation (or early presbyopia of the subjects), with the resultant blurring of the retinal image, a possible increase in optical aberration, the decrease in retinal illuminance with the decreased size of the pupil, a change in pattern of physiological nystagmoid eye movements, and also a possible artifact because of poor reproduction of the very small test objects required for near testing. As yet, no conclusive evidence exists that there is generally a significant change in visual acuity with viewing distance, and certainly individual differences would be expected.

In studies of stereopsis or, better, of stereoscopic acuity, the so-called secondary or empirical factors probably have a prominent part, especially when there

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are many familiar objects in the field of view. Even in carefully controlled test situations, care must be taken to eliminate changes in luminance, angular size, and color of the test stimulus that might occur with changes in distance of the test objects.

The elimination of these secondary or empirical factors in spatial localization has been one of the main problems with regard to data on stereoscopic acuity and viewing distance. Teichner and associates,[2-4] in experiments of visual depth discrimination in commonplace surroundings up to distances of 3,000 feet, reported a constant decrease in computed stereoscopic threshold with increasing distance, even to distances ordinarily considered beyond the limiting range of stereoscopic depth discrimination.

The difference in depth discriminated was interpreted as being due to stereoscopic depth, and, when the results were converted into equivalent angular disparity, extremely small equivalent thresholds were computed. The conclusions drawn from these data were of questionable validity. In a pilot study, Ogle[5] excluded empirical factors in determining stereoscopic thresholds for the two viewing distances of 0.5 and 10 M. Results indicated no significant difference in stereoscopic acuity at these two viewing distances. Jameson and Hurvich,[6] commenting on these results in presenting their own data on experiments from 3 to 48 M., concluded that stereoscopic acuity is constant and independent of distance, when the only stimulus is the change in angular parallax.

Subsequently, however, Amigo[7] reported that he had found a significant change in the stereoscopic thresholds in distances from 50 to 200 cm. He reported that his data showed an increasing stereoscopic acuity from 50 to 100 cm. and then a gradual decrease from 100 to 200 cm., although at 50 cm. and 200 cm. the acuities were nearly the same and therefore not contrary to the results of Ogle. He suggested that the change he found in stereoscopic acuity might best be explained on the basis of changes in the rhythm of microoscillations and saccades of the eyes at different viewing distances.

The present study was undertaken to clarify this situation, extreme care being taken to eliminate empirical factors.

Instrumentation

A schematic drawing of the haploscopic apparatus is shown in Fig. 1. The subject's head was held in the instrument by a suitable headrest and chin cup. The subject fixates an illuminated white plumb line, which is visible through a horizontal slit aperture cut in a near white screen and which is seen against a uniformly illuminated white background, in symmetrical convergence. The screen was illuminated by two 7 watt fluorescent lamps mounted in tubular housing above and below the aperture. The luminance of this background was adjusted to be the same as that of the near screen with the aperture. This arrangement provided constant light adaptation over a large visual field. The angular size of the fixation line was held relatively constant for all selected observation distances by the use of cord of different sizes. The fixation line was separately illuminated by flood lamps so as to appear brightly illuminated above the luminance of the background.

The subject sees, by reflection from beam-splitting mirrors (*M*) placed in front, the images of test lines, and these are perceived stereoscopically in the vicinity of the fixation line. One of the mirrors was kept stationary, while the other one could be rotated through exceedingly small angles about a vertical axis when activated by a suitable lever and a screw device. When the mirror is turned through a small angle, the transverse disparity between the images in the two eyes of the test lines relative to those of the fixation line is changed, and, correspondingly, the test line is perceived by the subject to move in stereoscopic depth farther or nearer than the fixation line. By means of a suitable dial indicator, the change in angle through which the mirror was rotated and, therefore, the change in the transverse disparity between the images of the test objects could be read directly. The dial indicator was calibrated prior to the experiment to be read in minutes of arc angular disparity.

The test lines consisted of two incandescent lamps with identical line filaments oriented vertically and mounted in a suitable and adjustable housing. In order to use the Badal principle, field lenses consisting of two +4.00 diopter lenses were inserted in the light paths from the incandescent

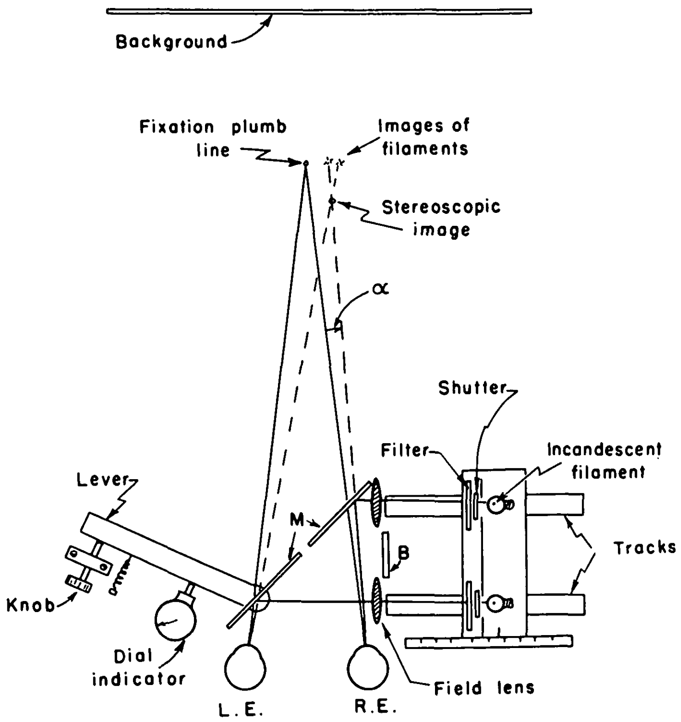

Fig. 1. Schematic plan of the apparatus used to measure stereoscopic acuity at various observation distances.

lamps to the eyes and positioned so that the posterior focal points of each of the lenses coincided with the entrance pupils of the corresponding eyes of the subject. By suitable adjustment of the distance of the filaments from the lenses, the image of each filament could be formed at any desired optical distance without there being a change in angular size, luminous intensity, or color. A central baffle *(B)* was so situated that each eye saw only one filament. Neutral density filters were placed before the filaments so that the brightness of the filaments was essentially the same as that of the illuminated fixation line. The test line was maintained at a constant angular position (α) of 1.03 arc degrees to the right of the fixation line for all observation distances. The brightness of the test images and the fixation line was kept the same.

Directly before each filament, special shutters were mounted. These consisted of lightweight blackened blades attached vertically to rotary solenoids. These shutters were fast acting, reliable, and constant. The exposure time afforded by them was accurately controlled by suitably designed driver electronic circuits and this exposure was monitored by means of a dual-beam oscilloscope. For the entire experiment, the exposure time was kept constant at 20 msec. For all practical purposes, the image on the retina would be essentially stationary for this duration of exposure, and if a small factor due to the length of exposure was present it would remain constant for all tests.

Artificial pupils, 3.0 mm. in diameter, were placed before each eye. These were used to avoid the possible effect of change in natural pupil size with change in convergence. A separate series of data was obtained, however, using natural pupils for all observation distances to establish to what extent control of pupil size was really important. The tests were conducted in a semidarkened room.

With this apparatus, the essential features so important to this study in eliminating empirical clues to depth were:

1. The eyes were light adapted to a constant photopic luminance by light from a uniform background of about 50 millilamberts.
2. Pupillary size was controlled by means of artificial 3.0 mm. pupils except in the series in which natural pupils were used.
3. The images of the test line maintained the same luminance, angular size, and sharpness of focus for all disparities and all stereoscopic depths.
4. The stereoscopic image of the test lines was maintained at a horizontal extrafoveal angle

of 1.03 arc degrees to the right of the fixation line for all observation distances, so that the same retinal areas were involved throughout the tests.

5. The vertical angular extent of the fixation and test lines remained constant.

6. The same shutter speed of 20 msec. was used for all tests.

7. The measurements of stereoscopic threshold were given directly in terms of angular disparity.

8. The stimulus to accommodation and convergence was held constant by fixation lines at each distance used.

9. The only stimulus for depth perception was the disparity between the images of the fixation and test lines.

Procedure

Three subjects whose ages were 30, 27, and 30 years, all with full range of accommodation, were used. All had 20/20 unaided vision in each eye. The refractive errors were: J. B., –0.25 –0.25 ×10, –0.25 –0.25 ×178; L. R., pl. +0.50 ×90 O. U.; and C. K., pl. +0.25 ×50, pl. +0.25 ×110. Two of the subjects (C. K. and L. R.) had had considerable prior experience in making stereoscopic observations. The third subject (J. B.) received extensive training prior to the experiments until data obtained were consistent.

The subject was seated and his head was adjusted to the instrument. Artificial pupils, when used, were adjusted so as to be centered with respect to the eyes and centered with respect to the instrument. The operator then adjusted the dial indicator to set the disparity to some value and gave a "ready" signal to the subject. The subject was directed to fixate the center of the fixation line and to trip the shutters by means of a trigger switch, which then operated the shutters simultaneously and thus exposed the test lines momentarily. He was then asked to report whether he had perceived the test line "nearer" or "farther" than the fixation line.

A range of disparities was then found by trial and error such that the end points were fairly consistent in that "near" and "far" responses were calculated. When these percentages were plotted against the disparity setting, they followed a typical psychophysical sigmoid curve.

Thus, the standard psychophysical procedure was followed, and from the data the disparity corresponding to the 50 per cent level and the disparity difference corresponding to the standard deviation σ were obtained by calculation using the weighted method of probit analysis.[8]

The 50 per cent level determines the most probable disparity for which the test line appeared at the same distance as did the fixation line. The standard deviation of the distribution, σ, in seconds of arc was used as the threshold or limen for stereoscopic depth in this study. The reciprocal of σ would be a measure of the stereoscopic acuity.

Seven observation distances were used: 6.0, 4.0, 2.0, 1.0, 0.67, 0.50, and 0.40 M., corresponding to a range of 0.16 to 2.5 diopters of stimulus to accommodation. Due to mechanical limitations of the apparatus set by the positions of the field lenses, the nearest observation distance that could be obtained was 0.40 M. For each subject a minimum of three sets of data, 300 observations in all, were taken for each observation distance. These distances were used in a random order. In some instances many more sets were taken. Measurements for each individual were taken over a two-month period.

Results and comment

The results for the three subjects are shown graphically in Fig. 2, together with the plot of the data of Amigo[7] for comparison. In these graphs the reciprocal of the observation distance (diopters) is plotted on the abscissa, and the measured stereoscopic acuity (reciprocal of σ in minutes of arc) is plotted on the ordinate. Inspection of the graphs for the three subjects shows that there is substantially no significant change in stereoscopic acuity with change in observation distance and therefore with accommodation—certainly none for observation distances greater than about 50 cm. The results illustrated in these three graphs do not agree with the results of Amigo.[7] They do support the results of Ogle's pilot study[5] in which no appreciable change in the angular disparity threshold for stereoscopic depth perception was found at the two observation distances of 0.5 and 10.0 M.

Fig. 3 is a composite graph of the mean thresholds of the three subjects to illustrate individual variation. Fig. 4 illustrates the mean thresholds of two subjects who obtained data with natural pupils and with 3.0 mm. artificial pupils. The graph indicates no significant difference in stereoscopic acuity in the two experiments when the factor of pupil is controlled. This result is probably in agreement with the reports of work[9] in which it was found that visual acuity changed little with pupil size in the range of about 2.5 to 5 mm. diameter.

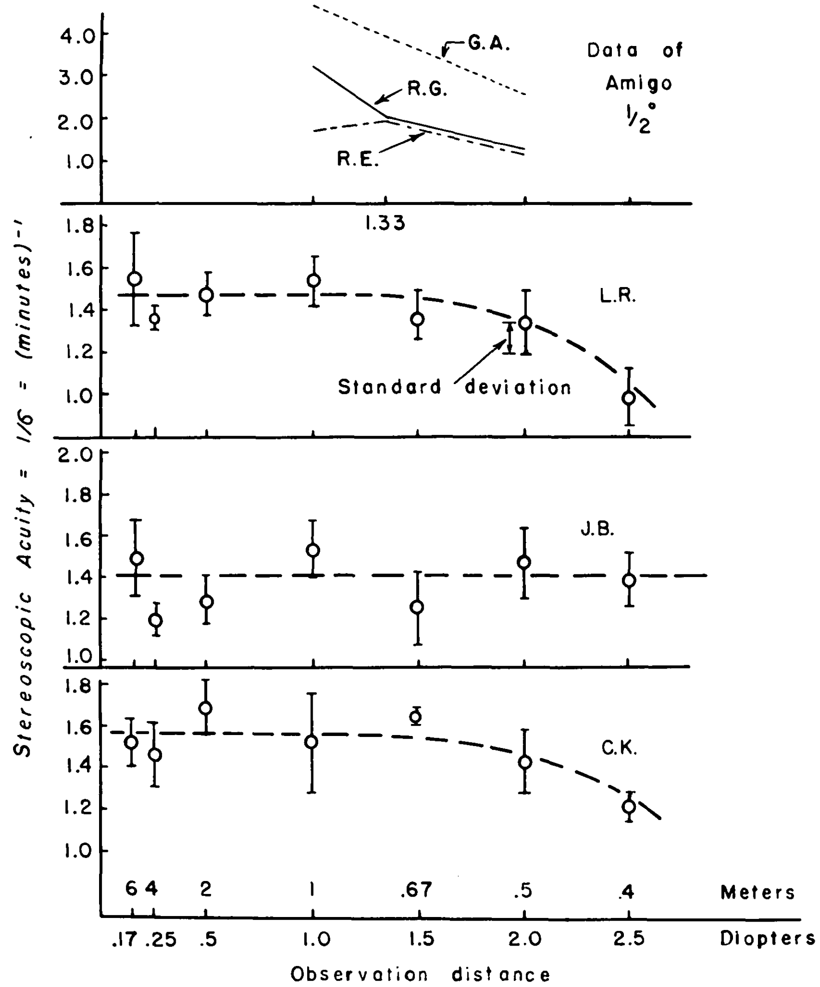

Fig. 2. Graphs showing mean stereoscopic acuities and standard deviations obtained for each of the three subjects. The small circles indicate the mean stereoscopic acuity of the several sets of data, and the lengths of the short vertical lines through these circles indicate the standard deviation from the several sets.

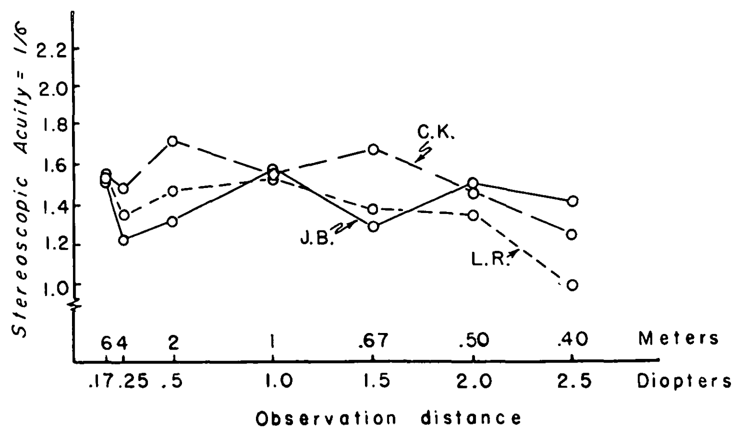

Fig. 3. Composite graph of the mean stereoscopic acuities of the three subjects.

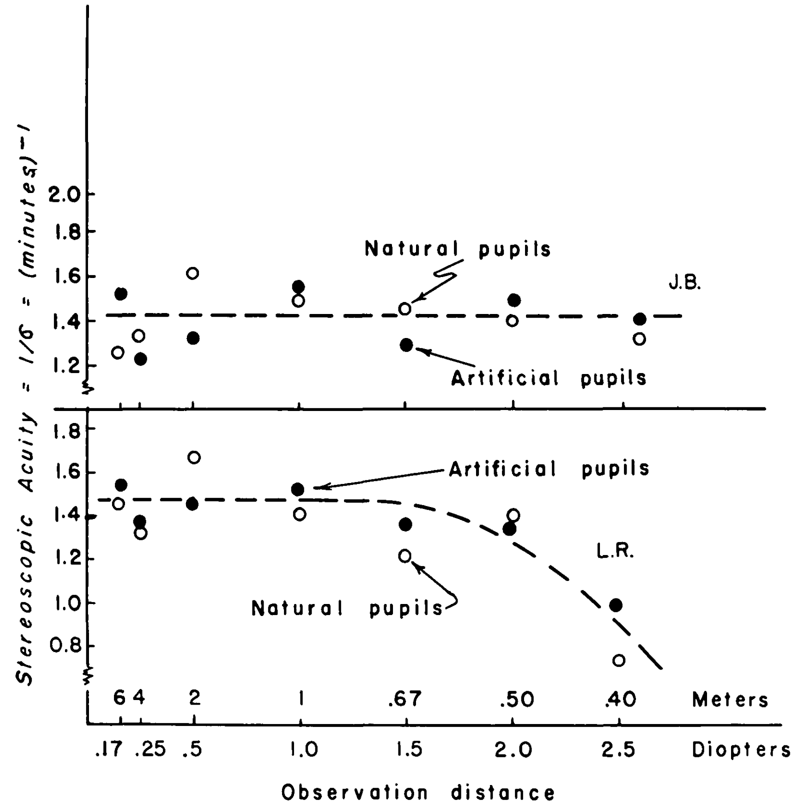

Fig. 4. Graphs showing little or no difference in stereoscopic acuities measured with natural or artificial pupils. The interrupted lines indicate the trend of the stereoscopic acuity with dioptric value of observation distance.

Two of the subjects in this study did show some decrease in stereoscopic acuity when the test stimuli were at the nearer observation distances from 50 to 40 cm. The third subject (J. B.) did not show this decrease, however. It would be a problem to account for this decrease without ancillary experiments being performed. The fixation line itself possibly is not a sufficient stimulus to full accommodation, and thus there would be some resultant blurring of the images. The influence of such blurring on stereoscopic acuity[10] cannot be predicted easily, although blurring could reduce visual acuity. A small degree of uncorrected hyperopia perhaps would exaggerate this lack of full accommodation. This result may be similar to that pertaining to visual acuity and observation distance.

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