[redacted]

Reprinted from JOURNAL OF THE OPTICAL SOCIETY OF AMERICA, Vol. 46, No. 2, 122–125, February, 1956
Printed in U. S. A.

R56-44

Effects of Target Separation and Distance on Commonplace Binocular Depth Discrimination

WARREN H. TEICHNER, JOHN L. KOBRICK, AND E. RALPH DUSEK
Quartermaster Research and Development Center, Natick, Massachusetts

(Received August 19, 1955)

Two experiments were performed to determine the effects of lateral target separation on commonplace binocular depth perception and to extend previous studies of the effects of distance to the range of 10 to 100 feet. Separations of 1.4 to 114.6 minutes were not found to have a differential effect except at the greater distances. This is attributed to a loss of visual rather than depth acuity. The effects of viewing distance were found to be consistent with previous studies of the distance effect. Differences in the effects of distance were found between sophisticated and unsophisticated subjects; the former tended to make finer discriminations especially at the greater distances.

INTRODUCTION

STUDIES of stereoscopic and vernier acuity strongly suggest that the lateral target separation of the standard and comparison targets have an important effect on the measures obtained.[1–9] It might be expected that the same effect would prevail upon commonplace depth discrimination since stereoscopic and vernier acuities appear to be related to this type of visual ability.[10,11] Nevertheless, those studies of the effects of target distance on depth discrimination out-of-doors in which the separation angle was held constant[10–13] at different target distances have yielded measures quite similar to those studies in which the angular separation was allowed to decrease[14,15] as the target distance increased. This suggests that, at least within some limits, the effects on commonplace depth discrimination of target separation may be so well compensated for by the presence of depth cues that it may be considered negligible. One purpose of the present study was to investigate this problem in some detail by varying the lateral separation of the targets at different viewing distances under commonplace viewing conditions and determining the effect on the precision of depth discrimination.

[1] G. G. Anderson and F. W. Weymouth, Am. J. Physiol. 64, 561 (1923).
[2] R. N. Berry, J. Exptl. Psychol. 38, 708 (1948).
[3] M. J. Hirsch and F. W. Weymouth, Arch. Opthalmol. 39, 224 (1948).
[4] A. Matsubayashi, Acta Soc. Opthalmol. (Japan) 41, 2055 (1937).
[5] K. N. Ogle, Arch. Opthalmol. (Chicago) 22(6), 1046 (1939).
[6] K. N. Ogle, *Researches in Binocular Vision* (Saunders, Philadelphia, 1950).
[7] K. N. Ogle, Proc. Phys. Soc. (London) B64, 289 (1951).
[8] A. A. Rady and I. G. H. Ishak, J. Opt. Soc. Am. 45, 530 (1955).
[9] W. D. Wright, Proc. Phys. Soc. (London) B64, 289 (1951).
[10] Teichner, Kobrick, and Wehrkamp, Am. J. Psychol. 68, 193 (1955).
[11] Teichner, Kobrick, and Dusek, J. Opt. Soc. Am. 45, 913 (1955).
[12] Dusek, Teichner, and Kobrick, Am. J. Psychol. 68, 438 (1955).
[13] Beebe-Center, Carmichael, and Mead, Aeronaut. Eng. Rev. 3, 1 (1944).
[14] Holway, Jameson, Zigler, Hurvich, Warren, and Cook, Div. of Research, Grad. School of Bus. Admin., Harvard Univ. (1945).
[15] M. J. Hirsch and F. W. Weymouth, J. Aviation Med. 18, 594 (1947).

A second purpose of this study was to extend previous investigations of the effects of viewing distance on commonplace depth discrimination. Those studies[10–15] of the distance variable which have been done were performed at distances ranging between 100 and 3000 ft. The results obtained indicate that the precision of commonplace depth discrimination decreases parabolically with distance. These studies also indicate that the binocular image disparity associated with this decrease in precision decreases parabolically. For these reasons it has been suggested[11] that the stereopsis angle, usually calculated as a measure of depth acuity, may be better conceived of as a measure of relative depth acuity. The present study was designed to further test and extend these findings by studying the effect of viewing distances of 10 to 100 ft.

PROCEDURE

The apparatus, experimental room, and conditions of illumination have been described in detail elsewhere.[12] Briefly, the study was conducted in a well-lighted, long, open basement. Two white three-in. square targets rode in hidden tracks in the center of a black table. The inside edges of the targets could be separated to a maximum of four in.

Two experiments were carried out. Two of the authors (WHT and JLK) served as the subjects in Experiment I. Three soldiers were used as subjects in Experiment II. These three subjects were given some preliminary training and were well acquainted with the kind of judgment required but they could not be considered highly sophisticated subjects at the beginning of the experiment. Both experiments were similar otherwise except for minor details which will be noted.

In each experiment all subjects were run in rotation, one setting at a time. In Experiment I subjects alternated acting as the experimenter. In this experiment there were two testing sessions per day, one in the morning and one in the afternoon, both under identical conditions of target separation and viewing distance. In each of these sessions each subject made six target settings, three with the comparison target approaching him ("far" setting) and three with it moving away from him ("near" setting). With combined morning and afternoon sessions this resulted in a total of 12 settings per subject per day available for analysis.

In Experiment II only one session was used each day. In this session each subject made a total of 24 settings, half of them being "near" and half being "far" settings. In both experiments only one combination of distance and target separation was studied per day. Distance was varied from 10 to 100 ft in 10-ft increments. Target separations of 0.5, 1.0, 1.5, 2.0, 2.5, 3, and 4 in. were used at each of the 10 distances in Experiment I. Except that a target separation of 2.5 in. was not used in Experiment II, this experiment employed the same conditions. The order of "near" and "far" starts was selected for each session in both experiments with a table of random numbers. Similarly, the order of separation-distance combinations was randomized for each experiment.

The various combinations of distance and target separation were such that although for a constant linear separation, the separation angle decreased with distance, there were present angles of equal magnitudes at the different distances. The most frequently repeated angular separation was 14.30′ which in both experiments occurred at each distance from 10 to 60 ft and at 80 ft; other angles, both larger and smaller, were repeated a lesser number of times but were repeated over different ranges of distance.

RESULTS

Although not of primary interest, the constant errors of the settings were determined in both experiments. These tended to be positive or negative according to whether the setting was a "near" or "far" one, but of approximately the same magnitude for both kinds of setting. There did not appear to be a systematic effect due to the experimental conditions, i.e., the constant errors did not appear to vary as a function of either target separation or distance.

The statistic of primary interest was the standard deviation of the settings (SD) which was used as a measure of the precision of the settings. Since Experiment II was more reliable in the sense of its involving more subjects and a greater number of observations per subject, it was selected for the more detailed statistical analysis. The individual SDs obtained were normalized with a transformation described previously[11] and an analysis of variance of the transformed data was performed. This analysis indicated that the main effects of Subjects, Distance, Separation, and the interaction of Distance and Separation were all significant at the 0.01 level of confidence. However, inspection of the actual SDs failed to reveal a systematic change in precision either due to the linear target separation at a given distance or the size of the angular separation. In order to reduce the variability of the measures and thereby increase the possibility of detecting trends,

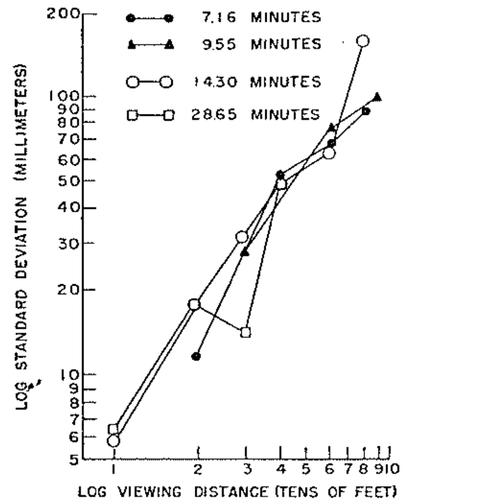

FIG. 1. Comparison of the effects of angular target separation on depth precision at different viewing distances.

SDs based on the data of all three subjects were calculated for each combination of conditions. Inspection of these data again failed to reveal anything very systematic. This can be confirmed by inspection of Figs. 1 and 2. Figure 1 is a log-log plot of the group SDs *versus* viewing distance for the four most frequently repeated angular separations. Although the range of distance covered by each of the lines in this figure is different and although considerable variability appears to be present, the four lines are still essentially the same. Another way to show this is to plot all of the data in terms of the linear separations at each distance and to connect in the graph those points representing

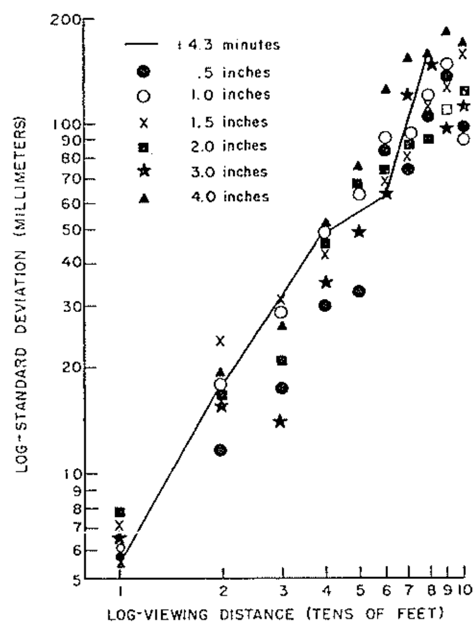

FIG. 2. Comparison of the effects of linear and angular target separations on depth precision at different viewing distances.

the most frequently repeated angular separation. Figure 2 shows the data handled in this fashion. The connected points represent a constant separation of 14.30′. This, of course, represents a different linear separation at each distance. The other linear separations used may then be compared both with each other in terms of consistency of order at each distance and in terms of the degree to which the connected line represents all of them. Inspection of this figure reveals a more or less haphazard order of arrangement of the individual separations at each distance and also shows that the line of constant angle provides a not too unreasonable fit to all of the separations at least up to 80 ft where it ends.

In order to determine to what the statistical significance of the separations was due, a χ_R, rank test,[16] was applied to the separation data of each subject. For the three subjects of Experiment II, the main effect of linear separation was found to be significant at the 0.01, 0.05, and 0.20 levels of confidence, each. Thus, the hypothesis that separation had no effect must be accepted in the case of one subject, at least. Inspection of the data of the two subjects having significant separation effects suggested that the significance might be due to the presence of one or two extreme measures at the four in. separation at the greater distances. The test was repeated, therefore, on the data of these subjects, but this time the row representing the four in. separation was omitted. The results of this test indicated that the remaining separations did not differ among themselves more than would have been expected on a random basis. It may be concluded, therefore, that the four in. separation was the source of significance in the over-all test and that the effect of this separation was not consistently present.

In view of the results of the analysis of the separation data of Experiment II, only the χ_R test was applied to Experiment I. Application of the statistical test to the data of this experiment, separately for each subject, indicated that both the distance and separation effects were significant. Again, there did not appear to be anything systematic about the effects of the separations. In order to analyze this problem more thoroughly the χ_R test was applied, but this time to all of the data

TABLE I. Nonparametric significance tests of the separation effect at each distance.

Distance	χ_r^2	P
10	5.11	0.40
20	6.26	0.29
30	9.80	0.08
40	7.97	0.16
50	2.26	0.81
60	9.69	0.08
70	18.71	0.002
80	14.60	0.01
90	9.91	0.13
100	11.17	0.05

[16] M. Friedman, J. Am. Stat. Assoc. 32, 675 (1937).

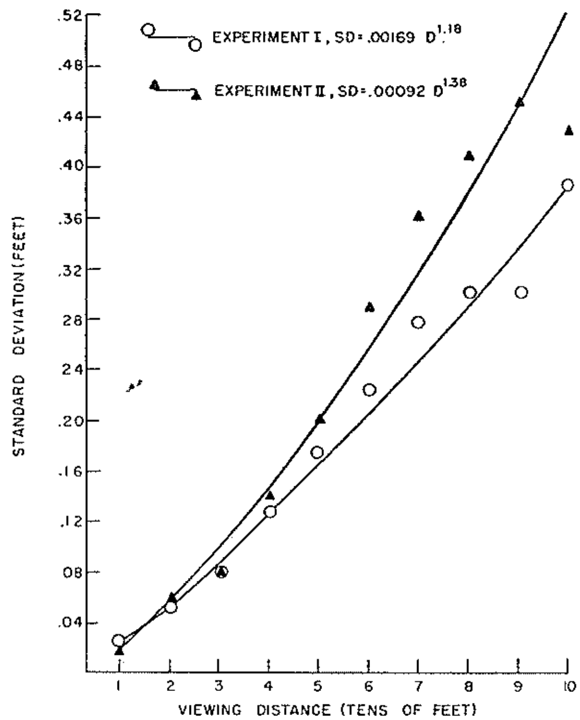

FIG. 3. Depth discrimination as a function of viewing distance.

obtained from all five subjects of both experiments. A separate test was applied at each distance to determine the effect of separation at that distance. For this purpose the 2.5 in. separation had to be omitted from the data of Experiment I as this separation was not used in the second experiment. The χ_R values obtained and their probabilities are presented in Table I. This table shows that separation had an effect significant at the 0.05 level or better only at 70, 80, and 100 ft.

The essentially linear relationships of Figs. 1 and 2 suggest that the increase of SD is a parabolic function of distance. To obtain the most generalized expression possible, SDs were calculated based on all of the data obtained at each distance without regard to separation. This was done separately for each experiment. A function, KD^j, was then fitted to each of the sets of points obtained using the method of least squares. The results may be seen in Fig. 3.

Inspection of Fig. 3 indicates that the same kind of distance effect was obtained in both experiments; the SD increased systematically throughout the range of distances involved; the same general type of expression fits both sets of data fairly well. On the other hand, although the SDs obtained at the near distances were approximately the same for the two experiments, the two curves begin to diverge at 40 ft, the SDs of Experiment I being smaller. With further increases in distance, the difference between the two sets of SDs tends to become larger.

In order to determine the effect of distance on the binocular image disparity associated with the values of

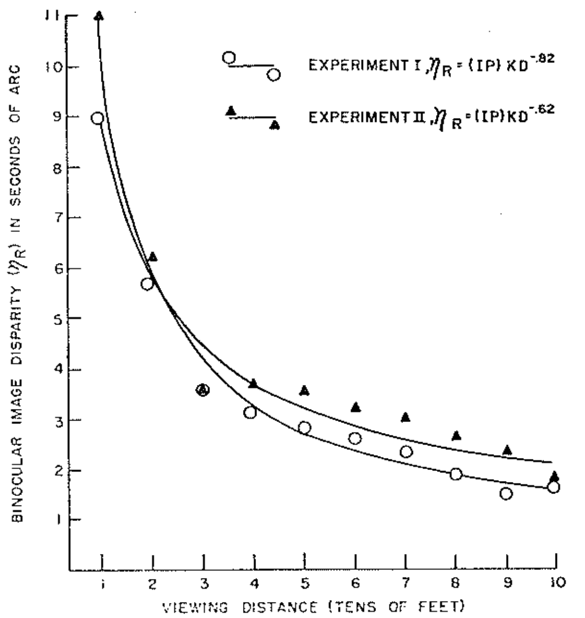

FIG. 4. Binocular image disparity as a function of viewing distance.

Fig. 3, the data were converted to angular measure and plotted as shown in Fig. 4. The smooth lines shown in this figure were derived from the equations fitted to the data of Fig. 3. The same general similarities and differences between the two experiments noted in Fig. 3 also hold in Fig. 4. In addition, it can be seen that the angular measure tends to decrease parabolically with distance in both experiments.

DISCUSSION

The most plausible interpretation of the effects of the target separations appears to be that only the widest separation had a reliable effect on the measures and this only at the extreme distances. It seems more likely that this is the result of an impairment in visual acuity than a direct effect on the mechanisms of depth discrimination. It has been shown that lateral separation may be expected to have an effect on both vernier and stereoscopic acuities[1–9] and presumably both of these are involved in commonplace depth discrimination.[10,11] However, the present results suggest that the effects of separation are probably negligible compared to the effects of the other factors involved, at least within relatively easy visual ranges.

The effects of viewing distance could have been predicted from previous results.[11] In the case of Experiment II which involved soldier-subjects, the results could have been predicted with fairly close numerical accuracy, i.e., the present curve describing the trend of precision was:

$$SD = 0.0009D^{1.38}, \qquad (1)$$

where SD is the standard deviation of the settings and D is distance, whereas the expression derived from out-of-door studies at long distances[11] was:

$$SD = 0.002D^{1.35}. \qquad (2)$$

This close correspondence of the two equations is very convincing evidence for the nature of the relationship. However, the present results indicate that when highly sophisticated (or motivated?) subjects are used the best fitting curve takes the form of:

$$SD = 0.0017D^{1.18}. \qquad (3)$$

Equation (3) approaches more closely to the results obtained by Holway *et al.*,[14] which were also based on very sophisticated subjects, than any others of the recent studies which have been performed.[10,11] Thus, it seems likely that although the function is parabolic, the parameters depend partly on nonvisual characteristics of the subjects. On the other hand, in view of the repeated findings that the exponent of distance is less than 2.00,[10,11,14] it must be concluded that the binocular image disparity associated with the precision of commonplace depth discrimination is not a constant, but decreases with increases in distance. It would not appear, therefore, to be a measure of binocular depth acuity, although it might still be a useful index of *relative* depth acuity.

SUMMARY AND CONCLUSIONS

Two experiments of commonplace depth discrimination were performed. In one, two of the authors serving as subjects made 12 settings at each of seven linear target separations each at ten viewing distances from 10 to 100 ft. In the second experiment each of three soldiers made 24 settings with six separations at the ten distances. Two white three-in. squares which rode on a hidden track in a long black table provided the standard and comparison targets.

The trends of the two experiments were very similar. Target separation had a significant effect, but only at the extreme distances and there not consistently or systematically. This suggests that the separations might have affected visual acuity, but only indirectly affected depth discrimination. The effects of distance were the same as in studies using longer ranges, i.e., both the precision of the settings and the associated binocular image disparity decreased parabolically with distance. Curves fitted to the soldier-subject trends yielded parameters numerically close to those obtained in previous studies using the same type of subject; curves based on more sophisticated subjects were similar in form but different in rate, i.e., precision decreased less rapidly with distance; binocular image disparity decreased more rapidly.