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Effects of Viewing Distance with the Howard-Dolman Apparatus

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Studies of depth acuity under commonplace viewing conditions have not found the effects of viewing distance to be in accord with stereoscopic theory of depth perception. To account for the results, it was proposed previously that vernier acuity may be the major basis for the quantitative discrimination of real depth; that binocular parallex, although important to the *impression* of depth and critical for stereoscopic vision, may provide at best only a weak quantitative aid to real depth perception. Such an explanation might have been erroneously forced from the "commonplace" studies performed since in those studies all target edges were always clearly defined for the subject and this might be expected to enhance coincidence-type depth clues without necessarily enhancing the stereoscopic clue. On the other hand, in the standard Howard-Dolman two-rod test upon which the "commonplace" studies were modeled, only the vertical edges of the rods are visible, and this might be expected to enhance the relative utility of stereopsis as a depth clue by reducing the effectiveness of vernier-type depth clues. This experiment was designed primarily to investigate this matter by studying the effects of distance with the Howard-Dolman apparatus.

It was found that a distance function derived earlier from the average acuities obtained in a "commonplace" study provided a very good fit to the average acuities obtained with the Howard-Dolman test. It was concluded, therefore, that the possible relative disadvantage of stereopsis as a clue in the "commonplace" studies did not affect the results obtained or vernier hypothesis proposed.

INTRODUCTION

STUDIES of real depth acuity under outdoor[1–5] or other so-called "commonplace" conditions have not found the effects of viewing distance on the depth threshold to be in accord with stereoscopic theory of depth perception. To account for the discrepancies noted, it has been proposed[4,5] that retinal spatial location (vernier acuity) of the target images may be the major basis for the quantitative discrimination of real depth, that binocular parallax although critical for stereoscopic vision and of importance in providing an *impression* of depth, may provide at best only a weak quantitative aid in real depth discrimination. However, such an explanation might have been forced erroneously from the "commonplace" studies performed since the very nature of the targets employed, i.e., four clearly visible target edges, would increase the opportunity of the subject to employ vernier clues in making his distance estimates. On the other hand, the standard Howard-Dolman two-rod test upon which much of stereoscopic theory has been based, and upon which the procedures of the commonplace studies were modeled, make available to the subject only two edges for each target, since only a portion of each rod is visible through the circular apertures. Thus, the subject's opportunity to use vernier clues may be considerably decreased and, consequently, he may rely more on stereoscopic factors. If this hypothesis is a good one, then as the viewing distance is increased with the use of the Howard-Dolman test, the linear depth threshold should increase as the square of the distance and the threshold parallactic angle should be constant. On the other hand, if the stereopsis hypothesis is not adequate, then the kind of distance function obtained from commonplace studies might hold and the vernier hypothesis, while not necessarily supported, would require further

[1] Beebe-Center, Carmichael, and Mead, Aeronaut, Eng. Rev. 3, 1 (1944).
[2] M. J. Hirsch and F. W. Weymouth, J. Aviation Med. 18, 594 (1947).
[3] Holway, Jameson, Zigler, Hurvich, Warren, and Cook, *Factors Influencing the Magnitude of Range-Errors in Free Space and Telescopic Vision* (Office of the Publication Board, Publication Board No. 40628, Department of Commerce, 1945).
[4] Teichner, Kobrick, and Wehrkamp, Am. J. Psychol. 68, 193 (1955).
[5] Teichner, Kobrick, and Dusek, J. Opt. Soc. Am. 45, 913 (1955).

TABLE I. Constant errors in centimeters of depth for each subject.

Distance (feet)	1 M[a]	1 B[b]	2 M	2 B	3 M	3 B
5	−10.4	+ 8.4	+23.2	+ 7.0	+ 89.1	+28.2
10	−19.3	− 5.2	+73.6	+35.2	− 1.0	+68.1
15	+ 1.8	+ 2.2	+ 4.5	+16.9	+101.7	+25.9
20	+ 7.4	+13.0	− 6.7	−53.0	+ 39.0	+25.4
25	+17.0	+21.6	+11.8	+28.2	+ 80.2	+72.0
30	+18.9	+ 1.2	+22.0	+12.0	− 20.6	+37.5
35	+ 4.0	+50.0	−31.2	−21.5	− 54.0	− 4.1
40	+45.9	+27.8	+16.7	+29.6	− 26.9	−10.3
45	−58.2	+17.8	+22.0	+29.0	+ 13.7	+45.0
50	−13.3	−15.9	+ 3.4	+ 1.9	− 19.3	+49.4

[a] Monocular (M).
[b] Binocular (B).

serious consideration. The purpose of the present study was to test these alternate hypotheses.

METHODS

Three soldiers served as subjects. Since these men had served in a previous study,[4] they may be considered as experienced or sophisticated subjects. As previously reported,[4] the subjects had normal visual acuity (20/20 Snellen, uncorrected) and better than average scores on the Verhoeff stereopter. In each daily testing session each subject alternated between monocular and binocular vision. The former was accomplished with the aid of an eye patch over the nonpreferred eye. At each viewing distance the subjects made 20 depth settings. Half of the starting positions were "near" and half were "far" settings. The order of "near" and "far" settings was varied with the aid of a table of random numbers; the initial starting distance of the comparison rod from the standard was varied irregularly. All three subjects were run in rotation, one setting at a time so that each one rested for two trials after each setting. Ten different distances from 5 to 50 ft were studied, but only one distance was used per day. The order of these daily distances was varied with a table of random numbers.

TABLE II. Standard deviation in centimeters of depth settings for each subject.

Distance (feet)	1 M[a]	1 B[b]	2 M	2 B	3 M	3 B
5	3.35	0.80	3.63	0.98	5.22	2.95
10	4.55	1.84	4.49	1.03	9.37	1.62
15	2.55	1.92	5.08	2.39	8.07	4.20
20	2.73	1.44	5.23	1.62	7.97	3.58
25	1.76	2.07	4.42	4.48	7.17	4.15
30	4.07	1.54	8.64	2.84	7.21	4.74
35	5.04	4.50	5.17	2.29	8.38	8.07
40	3.63	4.10	3.93	4.68	8.97	6.87
45	7.74	5.84	5.12	5.12	9.62	7.86
50	5.31	4.44	5.38	6.74	9.17	7.52

[a] Monocular (M).
[b] Binocular (B).

The apparatus was a standard Howard-Dolman test used to screen military drivers.* The subjects were allowed to manipulate the variable target with a long string until they were satisfied with its placement. The experiment was conducted indoors under moderate illumination.† The experimental room and the manner of its illumination have been described elsewhere.[6]

RESULTS

The constant errors of the settings were calculated for each subject and are shown in Table I. Inspection of this table does not suggest a systematic trend in the constant error with distance or a consistent difference between monocular and binocular vision. Both results are in agreement with most previous studies.

The standard deviation (SD) of the settings was calculated for each subject as a measure of precision or of depth acuity. These values are shown in Table II. Inspection of this table reveals that the SD tended to increase, though somewhat erratically, for each subject, and that binocular vision was generally superior to monocular vision. It was not considered necessary to perform statistical tests of these two kinds of effect since both have been demonstrated repeatedly before.

In order to obtain a more generalized estimate of the effects of the experimental conditions on the SD, the SD of all 60 settings provided by all three subjects was calculated for each distance and plotted in Fig. 1. It was assumed in doing this, that the inconsistencies noted in the distance trends of the individual subjects were the result of sampling error, that the "average" effect would provide a more reliable estimate than the individual trends, that, consistent with previous studies, the subject factor and distance do not interact, although real differences may exist between subjects. Finally, this procedure was desirable in order to compare the data with those of previous studies.

In Fig. 1 the monocular thresholds are joined by straight lines. These values tend to increase slightly and erratically over the range of distances studied. The binocular thresholds are not connected, but instead are plotted around a curve obtained by Teichner, Kobrick, and Dusek[7] for experienced subjects. This function was found to provide the best fit of all those previously obtained including the classical distance squared function. Since the present thresholds were slightly higher than those obtained by Teichner,

* Although the angular separation of the rods decreased with distance, this would not be expected to affect the distance function within the limits of this study as indicated by previous results.

† Approximately 50 ft-c at the subject's viewing positions. Since illumination was not optimum, higher than average Howard-Dolman thresholds might be expected. Inspection of Tables I and II confirm this. However, since illumination was the same throughout the experiment, this factor would not be expected to affect any of the trends obtained.

[6] Dusek, Teichner, and Kobrick, Am. J. Psychol. 68, 438 (1955).

[7] Teichner, Kobrick, and Dusek, J. Opt. Soc. Am. 46, 122 (1956).

Kobrick, and Dusek, it was necessary to add a constant to their equation. The resulting equation is

$$SD=0.0017D^{1.18}+0.0463. \tag{1}$$

The total algebraic deviation of Eq. (1) from the obtained values is +0.01; the total sum of squared deviations is 1.78.

Further inspection of Fig. 1 shows that the binocular SD's were considerably smaller at the nearer distances than the monocular SD's, but that the differences between them decreased systematically with increases in distance. The ratio of the monocular SD to the binocular SD decreased from 2.42 at 5 ft to 0.96 at 50 ft.

The reciprocal of the SD has value as an index of depth sensitivity[5,7] and is also useful in that since it decreases with viewing distance it changes in a manner consistent with the common meaning of a change in

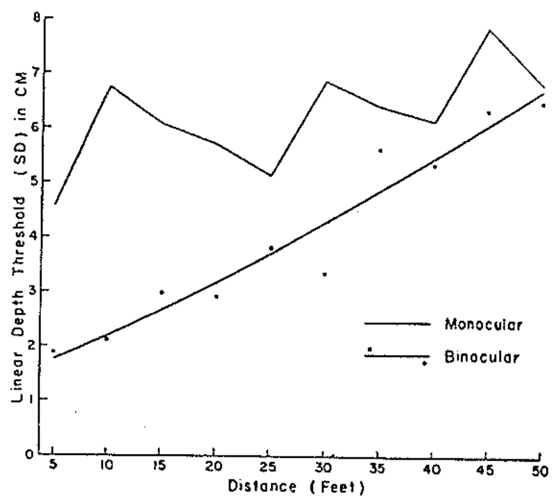

FIG. 1.

sensitivity or acuity. For these reasons, Fig. 2 was prepared. The data shown are actually 100/SD. This figure allows the same conclusions that were drawn from Fig. 1. Comparison of this figure with Fig. 1 shows, however, that the erratic nature of the monocular trend was smoothed out by the reciprocal function. As a result, Fig. 2 suggests an even smaller change in monocular sensitivity than does Fig. 1.

The threshold binocular image disparities associated with the binocular SD's of Fig. 1 are presented in Fig. 3. The smooth line drawn through the empirical points was derived from Eq. (1). This figure reveals very clearly that the threshold image disparity decreased systematically with distance.

DISCUSSION

Since the distance squared function was not able to describe the results, but instead a function obtained

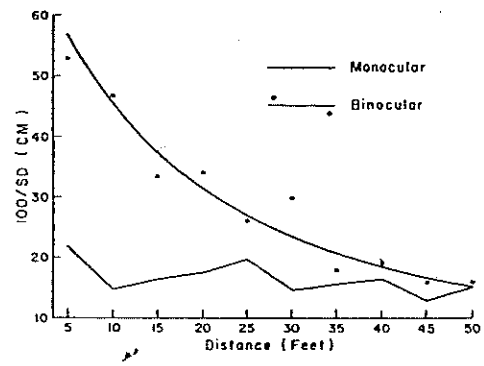

FIG. 2.

from a previous study using rectangular targets did provide a description of the results, it seems reasonable to conclude that the empirical generalizations obtained from "commonplace" studies have wide validity. The theoretical consequence is a reaffirmation of the notion that stereopsis is not as important an aid to the quantitative discrimination of real depth, as is usually supposed. While this does not necessarily support an alternate vernier hypothesis, it does make a different explanation desirable and the vernier hypothesis appears plausible.

The present data suggest that the number or characteristics of edges available to the subject is an important factor in the precision of his depth estimate since the present thresholds were slightly and constantly higher than those obtained with rectangular targets under very similar experimental conditions. This appears consistent with the vernier hypothesis, since the greater the number of comparison edges available, the greater

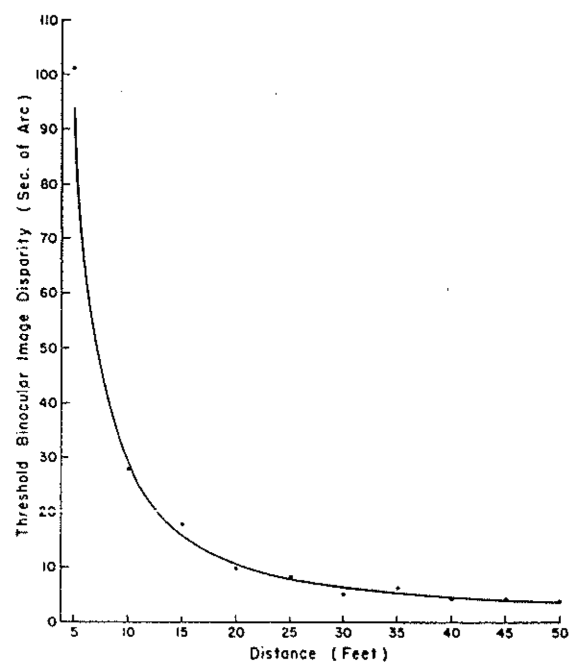

FIG. 3.

might be the precision of real depth based upon vernier-type estimates. This is not to imply that the vernier judgment depends on edge alignment as such, for, as Walls[8] has noted, it depends on differences in retinal position of the target images and such differences are occasioned when target edges are not in alignment. Other factors also affect the spatial arrangements of the target images, notably the visual angle of the targets. Thus, for two targets of identical physical size, the more distant target would occupy not only a different retinal area, but a smaller one. In the case of two test rods this means that the more distant rod would appear thinner than the nearer one. That it is the relative visual angle and not the actual angle subtended at the eye has been shown by Berry, Riggs, and Richards,[9] who reported that the actual width of the targets in the two rod case had no effect on either vernier or real depth acuity. Not only do their results make plausible the notion that both vernier and depth perception depend on relative visual angle, but since they found no difference between vernier and real depth acuities with the same subjects, they add further plausibility to the notion that real depth perception and vernier acuity are essentially the same.

It is of considerable interest that of those equations determined in previous studies,[4,5,7] one which was based upon sophisticated subjects fitted the present best. This is of interest because the subjects used in the present study were the only inexperienced ones who had been used in more than one study. Thus, it seems that there is a definite, quantifiable effect due to practice in the estimation of depth differences. As noted elsewhere,[9] the small exponent of Eq. (1) is the only one of those which have been obtained which approaches the results of Holway *et al.*[3] Since Holway and his colleagues used themselves as subjects and since they were all, presumably, "old hands" at this type of judgment, it seems reasonable to conclude that the apparently low thresholds that they obtained were to a large part due to practice and general sophistication. Thus, it would seem to be very important in future studies to state something of the degree of experience of the subject in making depth judgments under experimental conditions in order to make cross-experiment comparisons of threshold values.

The size of monocular-binocular differences found in the present study is consistent with previous studies conducted or discussed by the authors, but is not consistent with isolated comparisons reviewed by Hirsch and Weymouth[2] and Sloan and Altman.[10] As reviewed by these authors the monocular threshold has been found to be at least five or six times the binocular one at close distances. It is difficult to suggest the reason for this discrepancy in results. It might be due to differences in experimental procedures, sophistication of the subjects, visual anomalies, or it might not even be a significant discrepancy. The present monocular/binocular ratios are more nearly consistent with a statistical hypothesis adduced previously on the basis of which the ratios should be of the order of 1.44. All experiments which have varied distance have found that this ratio decreases with distance. In this regard the present results are not discrepant.

CONCLUSIONS

1. The empirical generalizations obtained from studies of depth perception under commonplace conditions have wide generality.

2. The classical hypothesis that stereopsis is the major basis of real depth perception is not acceptable.

3. Experience in making depth judgments reduces the depth threshold in a quantifiable manner.

[8] G. L. Walls, J. Opt. Soc. Am. 33, 487 (1943).

[9] Berry, Riggs, and Richards, J. Exptl. Psychol. 40, 520 (1950).

[10] L. L. Sloan and A. Altman, Am. Med. Assoc. Arch. Opthalmol. (Chicago) 52, 524 (1954).