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Commonplace Viewing and Depth Discrimination

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Measures of commonplace depth discrimination were obtained at observation distances of 200, 750, and 1500 feet in an Arctic area over flat terrain. Comparisons were made with similar measures taken over four different kinds of terrain (including an airstrip) in a desert area and with similar data reported by other investigators.

The results indicate that within a range of 100 to 3000 feet the standard deviation (precision) of depth discrimination is related to observation distance (D) approximately as the function, $D^{1.35}$. Within the same range the associated binocular image disparity decreases approximately as $D^{-0.65}$. It is suggested that for commonplace viewing the angle of disparity is better conceived of as a measure of relative depth acuity rather than of stereoscopic acuity.

The results also suggest that under the conditions studied commonplace depth acuity is 95–100% finer than stereoscopic acuity alone, binocular acuity is only slightly, if at all, superior to monocular acuity, and that the qualities of the terrain such as its texture have little or no effect. It was concluded that stereoscopic vision makes only a slight contribution to the precision of depth discrimination although it may be very important in producing a feeling or effect of depth. The hypothesis was put forth that vernier acuity is the major basis for commonplace depth discrimination.

INTRODUCTION

IN a previous study it was found that for daytime observations over a desert area commonplace depth discrimination depends strongly on viewing distance, but very little or not at all on the specific nature of the terrain over which viewing occurs.[1] Empirical formulas fitted to the data indicated that the thresholds of depth settings did not increase as the square of the observation distance as would be expected on the basis of studies of stereoscopic acuity, but increased at a slower rate. Accordingly, what would correspond to stereoscopic acuity as estimated from the data was found to increase with distance. Further, except for observations made over an airstrip, no differences were found between monocular and binocular vision. The findings were explained in terms of environmental factors which enhance vernier acuity and thereby extend depth sensitivity. If the conclusions of the previous study could be used to predict the results of a new study conducted under considerably different environmental considerations, then greater confidence might be placed both in their generality and the explanation offered. For this reason a second study was performed in an arctic area. The present paper reports this study and attempts to integrate the results with those of the previous study as well as with those of other relevant experiments.

METHODS

The data were collected near Churchill, Canada, during January and February, 1954. Observations were made over the muskeg during daylight hours. The experimental course appeared flat and, except for occasional sparse, short vegetation, was uniformly covered with a layer of snow. Visibility is usually good in this area except when ground wind speeds exceed approximately 15 mph. Under these conditions loose snow is blown up to form a haze. The present paper reports data obtained only on days when no haze was present.

EXPERIMENTAL PROCEDURES

Four soldiers served as subjects. In addition to normal medical requirements, each subject had 20/20 visual acuity (Snellen, uncorrected) and normal depth perception as measured on the Howard-Dolman test. Except for trial runs involved in setting up the apparatus, none of the subjects had had previous relevant experience with experimental depth judgments.

The apparatus was similar to that used in the previous desert study.[1] The only differences were slight variations in target dimensions due to the necessity of using a tracked vehicle (type Weasel) instead of a jeep as a mount for the variable target. The targets were rectangular boards, 66 in. wide and 72 in. above the ground, painted flat black. These targets were 2 in. wider and 5 in. shorter than those used in the desert. The standard target was mounted on the ground; the variable target was attached to the front end of the vehicle in a manner which concealed the vehicle from front view. The standard target was always to the subject's right.

A straight line laid out over the course with wire and light stakes acted as a guide for the driver of the vehicle. Positions of the standard target were selected with reference to this line so that a constant lateral separation angle of 3 min was maintained between the targets at all times. A canvas tape measure, marked in 0.10 ft, was staked into the ground between the two targets and used to provide a measure of the subject's equating error. At the distances involved in the experiment neither the guide line nor the tape appeared to provide a cue to relative distance.

[1] Teichner, Kobrick, and Wehrkamp, Am. J. Psychol. 68 (1955). In press.

All trials were administered in the same way. The subject stood at a selected distance from the standard target. The variable target was always started at an obviously unequal, but variable, distance from the standard and moved toward it at the slowest possible speed. Half of the trials were run with the comparison stimulus nearer to the subject than the standard and half with it farther away. The order of near and far starts was randomized for each subject. Subjects were instructed to observe the two targets and to signal by waving a large red flag when they appeared to be equally distant. No correction was allowed after the signal as the vehicle was stopped and the matching error read from the canvas tape.

Each testing session consisted of six monocular and six binocular target matchings for each subject. Subjects rotated through observations in a constant order so that each one rested for three trials following a single setting. Trials were alternately monocular and binocular. Between trials the subjects were sheltered in a tent out of sight of the experimental course.

TABLE I. Analysis of variance of constant errors.

Source	*d.f.*	*SS*	*MS*
Subjects (*S*)	3	251.46	83.82
Distance (*D*)	2	707.49	353.74[a]
Morning-Afternoon (*AM–PM*)	1	28.45	28.45
Monocular-Binocular (*M–B*)	1	32.88	32.88
S×D	6	162.23	27.03
S×AM–PM	3	10.69	3.56
S×M–B	3	296.88	98.96
D×AM–PM	2	21.25	10.62
D×M–B	2	42.08	21.04
AM–PM×M–B	1	0.56	0.56
S×D×M–B	6	790.28	131.71
D×AM–PM×M–B	2	10.18	5.09
S×AM–PM×M–B	3	49.42	16.47
S×D×AM–PM	6	91.50	15.25
S×D×AM–PM×M–B	6	189.42	31.57
Total	47	2684.77	

[a] $P<.01$.

Observations were made at viewing distances of 200, 750, and 1500 ft. To avoid possible effects of change in illumination, two sessions were run each day, one in the morning and one in the afternoon; both at the same observation distance. The observation distances for different days were selected at random.

RESULTS

An analysis of variance performed on the constant errors (*CE*) of the target settings is summarized in Table I. Inspection of Table I shows that the only variable in the experiment which had an effect on the *CE* was the observation distance. This effect is significant at better than the 0.01 level of confidence. Table II shows the actual *CE*'s. They are all negative indicating that the subjects consistently placed the variable target too near to themselves. Nevertheless, inspection of Table II reveals no systematic relationship between *CE* and distance, large *CE*'s being most frequent at the middle distance.

TABLE II. Constant errors in feet of individual subjects at different observation distances.

Subject	Distance (feet) 200	750	1500
1	−12.07	−41.33	−5.97
2	−22.57	−57.07	−49.92
3	−16.11	−49.54	−3.57
4	−13.47	−56.93	−28.82
Mean	−16.06	−51.22	−22.07

The statistic of major concern in the present study was the standard deviation (*SD*) of the settings which is used as a measure of the consistency or precision of the settings. Since the *SD*'s were based on small samples, a normalizing transformation was required before an analysis of variance could be performed. A three-dimensional table was constructed (subjects, monocular *vs* binocular and distances), each cell of which contained the *SD* under a given condition. The measures taken in the morning and afternoon were combined in this table. The *SD*'s in the cells of this table were ranked according to their magnitudes. The ranks so obtained were then normalized with the use of tables provided by Fisher and Yates.[2] Assuming that the measures of the experiment were randomly obtained from the same general population, then the normalized ranks for the subpopulations (conditions) should represent random samples from a normally distributed population of such ranks having a mean of zero and unit variance. An analysis of variance performed to test this statistical assumption is summarized in Table III.

Inspection of Table III shows that the only significant effect was due to variation of distance. It was observed previously that distance was the only condition which had a significant effect on the *CE*'s. However, unlike the *CE*'s, the effect on the *SD* was systematic. This can be seen in Table IV which presents both the monocular and binocular *SD*'s for each subject as a

TABLE III. Analysis of variance of snow terrain data.

Source	*d.f.*	*SS*	*MS*
Subjects	3	1.37	0.46
Distance	2	17.72	8.86[a]
Mon-Bin	1	0.01	0.01
Subjects×Distance	6	1.50	0.25
Subjects×Mon-Bin	3	0.21	0.07
Distance×Mon-Bin	2	0.12	0.06
Subj×Dist×Mon-Bin	6	0.66	0.11
Total	23	21.59	

[a] $P<.001$.

[2] R. A. Fisher and F. Yates, *Statistical Tables for Biological, Agricultural and Medical Research* (Hafner Publishing Company, Inc., New York, 1953).

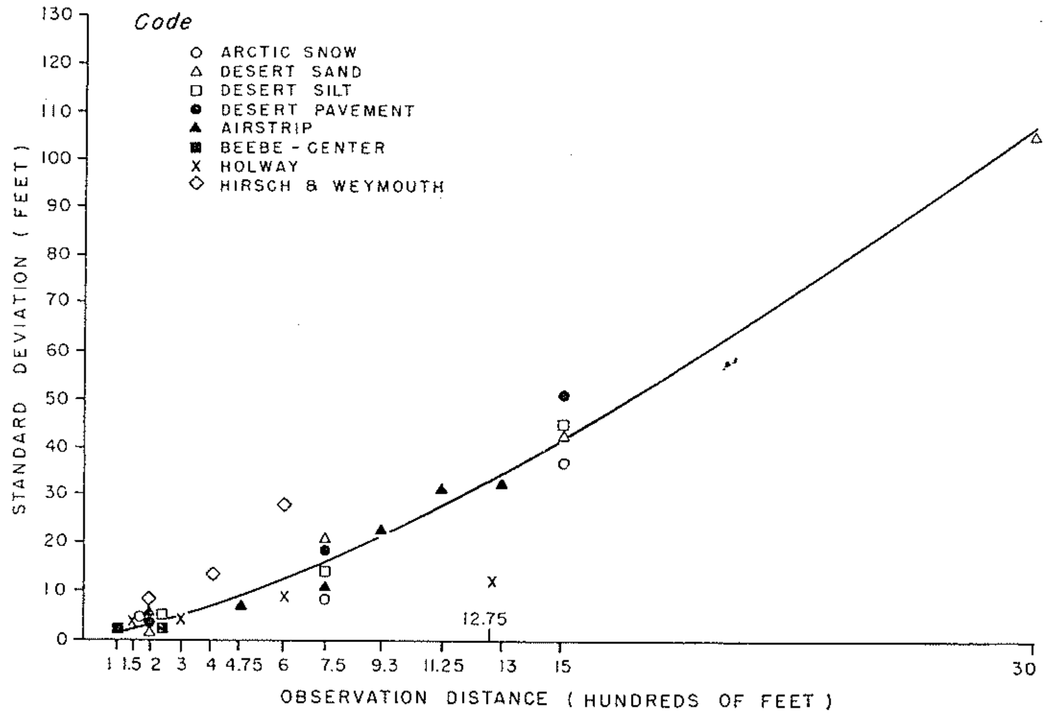

FIG. 1. Precision of depth discrimination as a function of observation distance.

TABLE IV. *SD*'s in feet of individual subjects viewing over arctic terrain.

	Viewing distance (feet)					
	200		750		1500	
Subject	Monocular	Binocular	Monocular	Binocular	Monocular	Binocular
1	2.23	3.27	12.70	7.88	26.23	24.08
2	3.83	3.05	4.91	3.95	35.69	31.82
3	2.34	2.26	14.55	13.65	22.61	28.53
4	3.70	3.84	12.70	9.90	58.50	60.13

function of distance. Although the statistical analysis did not reveal a significant difference between monocular and binocular vision, Table IV shows that at 750 ft, at least, binocular vision was consistently superior.

To obtain a more reliable estimate of the general effect of distance, *SD*'s for binocular vision were calculated. These were based on all 48 of the measures obtained from the four subjects at each distance. The *SD*'s obtained are presented in Fig. 1 along with the comparable measures obtained by Teichner, Kobrick, and Wehrkamp,[1] data reported by other investigators,[3–5] and an empirical fitted function.

Inspection of Fig. 1 indicates that the *SD*'s obtained in the present study are fairly comparable to those obtained when the view was over sand, silt, desert pavement or an airstrip. The values for arctic snow are generally lower at the three distances, the one exception being at 200 ft, where the *SD* obtained for viewing over snow is larger than the value for sand and about the same as that for silt.

In the desert study statistical analysis indicated that the differences among terrains were not random effects.[1] As Fig. 1 shows, however, the differences were not only small, they were very inconsistent. For this reason it was concluded that the significance found was probably due to uncontrollable and unnoticed differences which might have existed among testing areas and that, in general, the geographic texture of the terrain was not a significant variable. It is difficult to decide whether the present study has confirmed this conclusion since the terrain differences between the studies are confounded with differences between the two groups. In any case, considering the range of the observation distances involved and the similarities of the measures obtained, the differences among terrains do not seem systematic or consistent enough to conclude that terrain quality as such was an important parameter.

In the desert study an empirical formula, $KD^{1.517}$, was fitted to the airstrip data with considerable success.[1] The agreement of this equation with the present results was also quite good. However, in order to get a still more reliable description of the general effects of distance, a new curve was fitted, this time to all 19 of the binocular *SD*'s obtained from both the desert and arctic experiments. This new equation is the smooth

[3] Beebe-Center, Carmichael, and Mead, Aeronaut. Eng. Rev. 3, 1 (1944).

[4] M. J. Hirsch and F. W. Weymouth, J. Aviation Med. 18, 594 (1947).

[5] Holway, Jameson, Zigler, Hurvich, Warren, and Cook, *Factors Influencing the Magnitude of Range-Errors in Free Space and Telescopic Vision* (Harvard University Press, Cambridge, Massachusetts, 1945).

line of Fig. 1 and it may be seen to fit the desert and arctic values with fair accuracy. In order to evaluate the degree to which the equations fit our data and also to determine the adequacy of the expression, KD^2, which would be expected on the basis of stereoscopic theory, the mean square deviation of the 19 values from each of the three equations was calculated. The mean square deviation of the Eqs., KD^2, $KD^{1.517}$, and $KD^{1.35}$ are 1854.04, 18.72, and 12.03, respectively. Because the last equation had the lowest mean square deviation, it was selected as providing the best description of the results. Specifically, this equation is

$$SD = 0.002D^{1.35}, \qquad (1)$$

where SD is in ft and D is the observation distance in ft.

The SD's shown in Fig. 1 from a study by Beebe-Center, Carmichael, and Mead[3] were obtained by converting disparity angles read from the point of highest illumination on their Fig. 13 to SD's, the reverse of the process used by the authors to calculate the angles. Readings were made with the aid of a vertical reflecting projector. It will be noted that the values obtained are predicted very closely by Eq. (1).

The thresholds shown for Holway *et al.*[5] were converted from the mean deviations reported by those writers. The values obtained, like the mean deviations, are very small and are overestimated by the smooth line. The SD's shown for Hirsch and Weymouth[4] are the medians of the SD's reported in Table I of their paper. These were converted from meters to feet in order to make them comparable to our data. These SD's are underestimated by our prediction equation. When all of the values from all of the studies shown in Fig. 1 are considered, it can be seen that Eq. (1) represents the general effect of out-of-door viewing quite well.[6] *

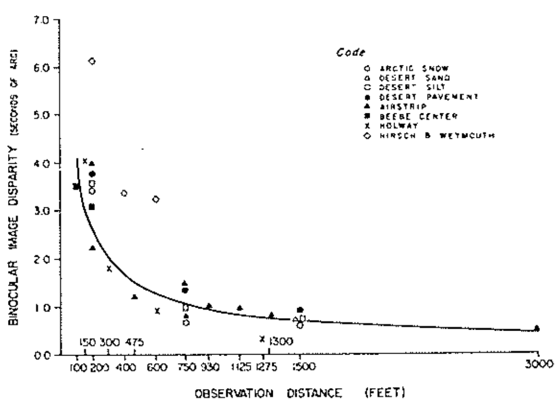

FIG. 2. Binocular relative depth acuity as a function of observation distance.

[6] W. S. Duke-Elder, *Textbook of Ophthalmology, Vol. II* (Henry Kipton, London, 1938).

* The mean square deviation of the three functions from the nine points of Fig. 2 *not* obtained by the present writers is 212.51 for KD^2, is 90.73 for $KD^{1.517}$, and 89.23 for $KD^{1.35}$. This is a considerable improvement in prediction of the distance-squared relationship, but it is still quite inferior to the predictions made by the other two equations.

In Fig. 2 are presented measures of the equivalent stereoscopic acuity derived from the values of Fig. 1. Again the values of Holway *et al.*[5] are very small and those obtained from Hirsch and Weymouth's[4] data are high compared to the smooth line and to those obtained by Beebe-Center, Carmichael, and Mead.[3] Regardless of these differences, the theoretical values derived from Eq. (1) predict the obtained values fairly well. Perhaps the most significant aspect of this figure is that angular measures of each study show a consistent decrease with increases in distance. The range of this decrease is from 4.07 sec of arc at 100 ft to 0.45 sec of arc at 3000 ft, based on values from the smooth curves shown.

DISCUSSION

Most discussions of depth perception assume that binocular depth acuity depends on binocular image disparity (stereopsis) and a variety of empirical, monocular factors. The most important of the latter are usually thought to be overlay, perspective, aerial perspective, lights and shadows, monocular parallax, relative sizes, and texture gradients of various sorts. Theorists in this area disagree as to the action of these factors on the perception, e.g., whether they act through learning or innate perception. Theorists also disagree regarding the relative importance of these empirical factors in the estimation of depth. In fact, practically the only point of agreement is that in addition to stereopsis, other factors are required for relative depth judgments, especially for distant vision.

Even though the relationship between monocular cues and depth perception is not known, the empirical laws governing stereoscopic vision are fairly well understood. It is generally accepted that the precision of stereoscopic depth decreases as the square of the visual distance, i.e.,

$$SD = KD^2, \qquad (2)$$

where SD is the standard deviation of a set of depth matchings, a measure of precision, K is a subject constant, and D is the visual distance.

Without attempting at this point to isolate the relative contribution of monocular factors, it may be assumed that in the out-of-doors situation most, if not all, monocular cues are operating together to provide depth information. The results of the present investigation indicate that under such conditions the precision of depth settings is improved considerably compared to what would be expected on the basis of stereoscopic vision alone. In fact, the present study indicates that the joint effect of monocular and binocular factors on the precision of the depth judgment may be described approximately by Eq. (1), or more generally by

$$SD = K'D^{1.35}, \qquad (3)$$

where K' is a constant which may or may not be equal to K in Eq. (2).

If we accept both Eq. (1) and (2), and if we assume that K and K' are equal or at least very close numerically, then the percent improvement in the precision of depth perception ($I\%$) under commonplace conditions over precision based on stereopsis alone is approximately:

$$I\% = \frac{D^{2.00} - D^{1.35}}{D^{2.00}} 100. \tag{4}$$

A plot of this percentage from 200 ft to 3000 ft is shown in Fig. 3. Inspection of this figure indicates that with the aid of both monocular and binocular cues, the precision of depth perception is increased 95% at an observation distance of 200 ft. As distance is increased, the percentage gain increases still more but at a very slow rate and appears to be asymptotic to 100%. Thus, although the relative contribution of the individual monocular factors is not indicated, the combined effect of all cues available to binocular vision produces a very large improvement over stereoscopic vision alone. This lends some indirect support to Ogle's[7] suggestion that, "It is highly probable that the stereoscopic sensation of depth is only roughly quantitative and when estimates of depth have to be made, the judgment does depend on empirical factors.

Further support for Ogle's hypothesis lies in a consideration of the differences between monocular and binocular viewing, or putting it another way, a consideration of the limit of stereoscopic vision. Under conditions where binocular vision is superior to monocular vision with respect to depth discrimination, a critical distance would be expected where this superiority was lost. This would be the distance at which the binocular image disparity was equal to the threshold of stereoscopic acuity. Depth perception from this distance on should be based entirely on monocular cues. The estimation of this critical distance depends, of course, on the stereoscopic acuity assumed. Graham[8] estimates this distance as 1500 ft and Ogle[7] as 2100 ft. In the desert study binocular superiority on the airstrip was actually lost at approximately 1900 ft.[1] Up to this point binocular vision was consistently, *but only slightly*, superior. These facts are accounted for by the present set of equations.

When the results are considered in terms of binocular image disparities (stereoscopic thresholds) it is found that the disparities which can be resolved in the presence of both monocular and binocular cues are extremely small. This would be expected, of course, from the small measures of precision which were obtained.

When stereopsis is the only cue, then the stereoscopic threshold (η) may be approximated by

$$\eta = C(IP)SD/D^2 \text{ sec of arc}, \tag{5}$$

[7] K. N. Ogle, *Researches in Binocular Vision* (W. B. Saunders, Philadelphia, 1950).
[8] C. H. Graham, *Handbook of Experimental Psychology* (John Wiley and Sons, Inc., New York, 1951), S. S. Stevens edition.

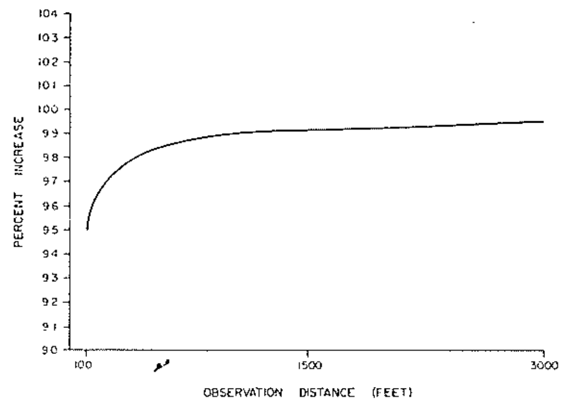

FIG. 3. Percent increase in precision of depth discrimination of commonplace vision over stereoscopic vision alone.

where (IP) is the interpupillary distance and C is a constant which converts the measure to sec of arc. If SD varies according to Eq. (2), then Eq. (5) may be written

$$\eta = (IP)KC = \text{const.} \tag{6}$$

However, the present results indicate that under normal viewing conditions the angular threshold not only is not a constant but it decreases with distance according to Fig. 2. If Eq. (3) is now taken to represent the SD for normal viewing, then

$$\eta = (IP)CK'D^{-0.65} \text{ sec of arc.} \tag{7}$$

This is the theoretical equation used in Fig. 2 and its behavior may be seen to conform reasonably to the results.

Now it might be questioned whether a situation involving pure stereopsis has ever been achieved. Ogle,[7] for example, in a situation presumed to approximate pure stereopsis presents data which show that the stereoscopic threshold decreases systematically through a distance of 20 cm to 6 m. Ogle also notes with respect to measures of stereoscopic acuity obtained by several investigators that values obtained at short distances (33–40 cm), "··· are usually higher than those obtained for more distant vision." [7] Presumably these failures of the distance-squared law are due to uncontrolled monocular factors, or in some instances other uncontrolled cues, e.g., proprioceptive cues involved in arm, hand or finger movements in those experiments where the subject operated the targets manually. In any case, the thresholds obtained are usually much higher than those reported in out-of-door studies. Both of these observations, i.e., higher thresholds and decreases in thresholds even through relatively short distances, lend support to the general conclusions we have drawn and suggest, in addition, that these conclusions might apply at short visual distances as well as the long ones studied.

Equations (6) and (7), taken literally, indicate that what we have called the "stereoscopic threshold (η)"

is not the same thing for normal viewing as it is for pure stereoscopic vision. Under the latter condition, its psychophysiological meaning is clear and conforms to the classical understanding, i.e., it represents the minimal resolvable angular disparity of the two retinal images and it is a constant. For commonplace vision it is variable, dependent on more than image disparity, and seems most useful as a measure of relative acuity or sensitivity. To keep the distinctions clear we shall refer to the true stereoscopic threshold as (η_t) and relative acuity or relative sensitivity as (η_R). The *SD* may be considered a measure of absolute precision and the reciprocal of the *SD* a measure of absolute sensitivity. It is clear that with increases in visual distance under normal viewing conditions depth perception decreases in absolute precision and sensitivity, but increases in relative sensitivity.

Although the present data do not lend themselves to an analysis of the relative contributions of individual monocular factors, they do allow some consideration of the nature of these factors. With the exception of Beebe-Center, Carmichael, and Mead,[3] all of the out-of-door studies reported involved the ground in the visual field. This one was performed with a level line of sight 35 ft above the ground at distances of 100 and 200 ft. Under these conditions it is inconceivable that the terrain could have affected the matchings. Nevertheless, our empirical formulas (Eqs. (3) and (7)) predicted their results fairly closely. Furthermore, although the desert and arctic data indicate that there were differences in depth acuity at the various test sites, these differences could not be attributed to the systematic effect of terrain qualities. We conclude, therefore, that the geographic qualities of the terrain, e.g., its texture gradient, have little or no effect on quantitative depth settings.[9] It may, of course, have a very important effect on judgments of absolute distance.†

Teichner, Kobrick, and Wehrkamp[1] suggested that the differences which they observed among terrains were probably due to slight variations in the slope of the target areas used. Dusek, Teichner, and Kobrick[10] demonstrated that a rise from the level of as little as one percent could markedly lower the threshold. It was observed that on one terrain (the airstrip) where a rise of about this amount was known to be present at two different target areas both monocular and binocular thresholds were considerably lower than would be predicted from the general trend of the data. According to Dusek, Teichner, and Kobrick[10] a similar lowering of the threshold would be expected if the target area were flat, but the subject was on a slight rise so that the slope of the line of sight to the targets was negative, i.e., in a downward direction.

Now it is clear that as the variable target is moved over a sloping target area there will be greater changes in the monocular retinal alignment or misalignment of the target images with respect to each other than there would be for the same changes in longitudinal distance on a flat target area. This might produce a greater change in the apparent heights of the two targets and in other monocular, empirical cues, but descriptively the basic change is only one of relative retinal positioning. The minimal resolvable misalignment of the target images so produced is the definition of vernier acuity and this acuity has been frequently observed to correspond closely to depth and stereoscopic acuities. In light of this and the findings that binocular depth acuity is slightly or not all superior to monocular depth acuity it seems reasonable to hypothesize that the major cue for commonplace depth discrimination is vernier image alignment, that the stereopsis angle and also the usually cited empirical, monocular factors are primarily effective in eliciting a feeling or quality or effect of depth which at best provides only a weak aid to the subject in making his depth matchings.

On the basis of this hypothesis, i.e., that vernier acuity is the primary basis for commonplace depth discrimination, certain other results become understandable. Thus, it has been reported that vernier acuity increases with distance.[11] This would account for the increase in relative acuity (η_R) with increases in distance found in the present study.

An experiment of considerable relevance has been performed by Berry.[12] In this study comparisons were made of depth thresholds obtained both monocularly and binocularly under three different experimental conditions: (1) When targets were arranged so as to provide only vernier cues, (2) when targets were arranged so as to provide stereoscopic cues, and (3) when targets were arranged so as to provide real changes in depth. All three subjects made observations under all conditions with the left eye only, the right eye only, and both eyes. The visual distance in all cases was 4622 mm which it should be noted, lies well within the range of near vision. Berry concluded from his results that in binocular vision real and stereoscopic depth thresholds are equal and smaller than vernier thresholds. He also concluded that the size of the difference is too great to be accounted for in terms of a simple summation of two separate monocular vernier components. Now Berry's data are critical to our thinking because if it can be shown that stereoscopic acuity when isolated provides a considerably better, or even as good a basis

[9] J. J. Gibson, *The Perception of the Visual World* (Houghton Mifflin Company, Boston, 1950).

† For an extensive discussion of the possible effects of texture gradients associated with the terrain on both relative depth and absolute space perception see reference 7.

[10] Dusek, Teichner, and Kobrick, Am. J. Psychol. 68 (1955). In press.

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

[12] R. N. Berry, J. Exptl. Psychol. 38, 708 (1948).

for depth acuity as vernier alignment, then it must be conceded that stereopsis is a primary cue in the judgment of relative depth rather than a secondary, weak one as we have suggested. This can be demonstrated if judgments based solely only on binocular parallax are as effective as those based only on vernier acuity. One qualification exists: In order to demonstrate this, it is necessary to show that stereopsis was the only factor involved in the binocular threshold. If we accept Berry's conclusion that his real depth and stereoscopic thresholds were not different, then we must also admit the possibility that either he did not have pure stereoscopic vision or that his real depth threshold was a case of pure stereoscopic vision.

It is instructive to consider Berry's data under the conditions where monocular and binocular comparisons were made of the three visual situations. These data are presented in Table II of Berry's paper which gives a comparison of the three kinds of threshold for each of the three subjects with the right, the left, and both eyes. Since Berry did not report a statistical analysis of these data, we performed an analysis of variance in order to determine the significance of the various effects. A summary of this analysis is presented in Table V where it may be seen that there is not a single main effect or interaction which is significant at the 0.05 level of confidence. However, because Bartlett's test of homogeneity indicated that there was significant heterogeneity in the data, it was considered worthwhile to make a detailed inspection of the actual differences in the table. In order to do this in a manner most relevant to our problem, Berry's data were used to calculate pertinent ratios of monocular to binocular vision and of vernier to depth acuity. These ratios are presented in Table VI which shows for each of the three subjects in Berry's experiment: (1) the ratio of the monocular real depth threshold to the binocular one, (2) the ratio of the monocular threshold to the binocular one under stereoscopic conditions, and (3) the same ratios separately based upon the right and left eyes of the subjects. In addition, Table VI shows the ratio of monocular vernier acuity to binocular stereoscopic acuity and to binocular real depth acuity, again for each eye separately.

The first thing that stands out in Table VI is the small size of the ratios. It is clear that there were no

Table V. Analysis of variance of Berry's data.

Source	*d.f.*	*SS*	*MS*
Subjects	2	2.6844	1.3422
Vision	2	2.4355	1.2178
Eye(*s*)	2	2.6180	1.3090
$S\times V$	4	0.8141	0.2035
$S\times E$	4	3.6312	0.9078
$V\times E$	4	2.6558	0.6640
$S\times V\times E$	8	2.7675	0.3459
Total	26	17.6065	

Table VI. Ratio of monocular to binocular depth acuity calculated from Berry's data.

Subject	Mon real/ bin real Eye Right	Left	Mon stereo/ bin stereo Eye Right	Left	Mon vernier/ bin real Eye Right	Left	Mon vernier/ bin stereo Eye Right	Left
RLS	1.44	2.04	1.06	1.96	1.79	1.90	1.48	1.57
CPD	1.45	1.37	2.12	1.23	1.86	1.50	1.73	1.40
LAR	1.28	1.18	1.14	1.61	1.24	1.18	1.13	1.08

conditions under which binocular acuity was considerably greater than monocular acuity although it was consistently greater. The range of these ratios regardless of subject or condition is from 1.06 to 2.12. This suggests also that the differences among conditions were very small. Thus, the same range, 1.06 to 2.12, represents the range of monocular/binocular ratios for stereoscopic and real depth. The monocular vernier/binocular depth thresholds ranged from 1.08 to 1.90. This suggests very strongly that the kind of monocular component involved was the same in all cases. In other words, it suggests to us that monocular vernier acuity underlies all of these ratios regardless of differences in the three experimental arrangements; that binocular depth acuity, if actually superior to monocular acuity was so due to the slight contribution of stereopsis as a cue. Further support for this contention may be found in other data in Berry's table, not reported here, which indicates that binocular vernier acuity was either no better or possibly not as good as monocular vernier acuity. Poorer binocular vernier acuity might be the result of unequal visual acuities of the two eyes of each subject or it might mean that the subjects were receiving disparate stimuli of a sort such as to impair the binocular vernier judgment of "left" or "right," but which could enhance the stereoscopic judgment of "near" or "far." That one of these two hypotheses is tenable can be shown by calculating the ratios of the separate acuities of the two eyes, larger threshold/smaller threshold. The range of these ratios, when calculated is 1.06 to 1.85 which is approximately the range of the ratios of Table VI. Thus, if anything can be concluded from Berry's data, it is that binocular depth acuity is only slightly finer than monocular depth acuity, if at all, and that if it is, it is due to the slight additional cue value of stereopsis. This, of course, is in complete agreement with our hypothesis.

It is interesting to speculate about one further possibility. If we are justified in extending Crozier's[13] statistical conception of bisensory and monosensory intensity discrimination to the present problem, we would hypothesize that binocular depth acuity is better than monocular acuity because the sample of neural elements available is twice as large. Accordingly, it would be expected that binocular acuity should be

[13] W. J. Crozier, Proc. Natl. Acad. Sci. Wash. 26, 54 (1904).

related to monocular acuity by a factor, $\sqrt{2}$, or 1.414. Inspection of Table VI indicates that 1.414 is a very representative number for the ratios obtained. Thus, Berry's data, if significant, may be accounted for without reference to stereoscopic vision at all. They cannot, therefore, be considered as opposing our hypothesis.

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