Vision Res. Vol. 9, pp. 1079-1094. Pergamon Press 1969. Printed in Great Britain.

THE SENSING OF RETINAL SIZE[1]

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(Received 1 July 1968; in revised form 19 February 1969)

THE PREVALENT view regarding size perception is that the core stimulus for perceived size is retinal size; the effect of cues of distance being only such as to modify the size perception away from retinal size and toward object size (cf. HOLWAY and BORING, 1942). Implicit in this view is the assumption that, as cues to distance are removed, perceived size is increasingly dominated by retinal size (visual angle). In other words, as depth cues are reduced, perceived size becomes increasingly determined by retinal size and increasingly independent of any distance cues that remain. An opposing point-of-view is expressed by the size-distance invariance hypothesis. The usual form of this hypothesis is that

$$S' = K\theta D' \tag{1}$$

(KILPATRICK and ITTELSON, 1953) where S' is the perceived size of an object of visual angle θ, D' is the perceived distance of the object from the observer and K is an observer constant. In more general form, the size-distance invariance hypothesis states that for a constant value of θ, S' is a monotonic increasing function of D'. It follows from this hypothesis that a perceived size cannot occur without a perceived distance, i.e. a perceived size is possible only when a perceived distance also is present.

The perceived size that would be expected to occur unrelated to, or in the absence of, perceived distance will be termed the direct perception of retinal size. Under reduced conditions of observation, if it can be demonstrated that S' occurs independently of D', a direct perception of retinal size can be assumed to have occured in opposition to the size-distance invariance hypothesis. On the other hand, if the resulting S' is related to D' in the manner described by equation (1), or by the more general form of the size-distance invariance hypothesis, the postulate of a direct perception of retinal size is unnecessary.

A variety of studies are pertinent to the problem of the direct perception of retinal size (cf. BAIRD, 1964; EPSTEIN, PARK and CASEY, 1961; WALLACH and MCKENNA, 1960; ROCK and MCDERMOTT, 1964) and reflect its continued theoretical importance. The usual approach has been to determine the stimulus values required to produce equal values of S' under conditions in which concomittant values of D' do not, or would not be expected to, occur. Since a number of methodological and interpretive issues are involved, a discussion of these studies will be presented elsewhere (GOGEL, 1970).

The basic procedure used to investigate this problem in the present study involves presenting different retinal sizes of a luminous rectangle, one at a time, under reduced conditions of observation. The size-distance invariance hypothesis will be applied to the results obtained from these conditions. Only the S' and D' values from the first presentations, however, are pertinent to the problem of the direct perception of retinal size, with the results from successive presentations reflecting the changes in S' and D' occurring from the relative size cue to distance.

[1]This study was supported by Grant NGR 05-010-010 from the National Aeronautics and Space Administration. The author wishes to thank Robert Newton and Jane McCarthy for their help throughout this study.

EXPERIMENT I

Apparatus

In this experiment three sizes of a luminous rectangle with a height to width ratio of 1·55 and a luminance of 0·1 ft-L. (as measured from the position of the observer) were presented to the observers one at a time. The visual angles of the width of the rectangles were 428′, 128′, and 64′. The rectangles were viewed in an otherwise totally dark field. A point source, rear projection system (GOGEL and MERTENS, 1966) was used to produce lighted rectangles on a screen located to the right of the viewing position at a distance of 13·0 ft from the observer. The images of the rectangle were reflected by a mirror into the observer's right eye and appeared directionally straight ahead. The viewing position, containing a head and chin rest and a viewing aperture with a shutter, was part of a booth that was kept totally dark throughout the experiment. Neither the viewing aperture, the mirror, nor any other objects or sources of light except the rectangle was visible to the observer at any time during the experiment. None of the observers were acquainted with the size of the room extending beyond the observation booth.

Both perceived distance and perceived size were measured in the experiment. The observer indicated perceived size by adjusting with his hands (kinesthetically) the lateral distance between two small posts, invisible to the observer, located at about the level of his waist. A meter stick attached to the apparatus allowed the experimenter to read the lateral separation between the posts from a position also invisible to the observer. Perceived distance was measured by verbal reports. Throughout this study an electrical communication system permitted the experimenter to speak with and to hear the observer and at all other times provided a background of white noise to mask any sounds associated with the changing of the stimulus conditions.

Observers

The observers in all four experiments of this study were men and women enrolled in an introductory course in psychology. All had a visual acuity (both near and far) of at least 20/20 in their right eye (as measured with a Keystone Orthoscope), *with only the right eye (monocular observation) used throughout this study*. None of the observers were acquainted with the purpose of the experiments, and none served in more than one of the experiments. Sixty observers were used in Experiment I.

Procedure

All three sizes of the rectangle were presented in counterbalanced order to every observer. The instructions were in part as follows: "This is an experiment on how people perceive objects. You will be asked to indicate what you perceive the size and distance of objects to be. When we ask you to indicate the distance of an object, we want you to tell us how far the object appears to be from your eyes. When we ask you to indicate the size of an object, we want you to indicate how wide (left-to-right extent) the object appears to be." Before being presented with any of the rectangles, the observer remained in the totally dark observation booth for 10 min, in order to lessen the possibility that judgments of relative retinal size would occur between past stimulation and the rectangular stimulus of the first presentation of the experiment. One verbal report of apparent distance (expressed in feet or inches or in some combination of both) was obtained for each size of rectangle for each observer. Following each distance report, two apparent width measurements were obtained in which the observer kinesthetically adjusted the lateral distance between the rods, until this distance was the same as the apparent width of the object. For one width adjustment the starting position of the rods was together and for the other far apart. The average of the two width adjustments constituted the width score for that observer on the particular size of rectangle. Throughout this study, both distance and width responses were obtained on one size of rectangle before the same observer was presented with a rectangle of another size.

Results

The results from Experiment I are shown in the upper portion of Table 1. Each of the entries are based on 20 scores, one from each observer. Both means and medians are given,

TABLE 1. PERCEIVED DISTANCE D' AND PERCEIVED WIDTH S' OF THREE RETINAL SIZES OF A RECTANGLE PRESENTED IN AN OTHERWISE DARK VISUAL FIELD

	First presentation			Second presentation			Third presentation		
				Experiment I					
Visual angle (θ)	428′	128′	64′	428′	128′	64′	428′	128′	64′
Mean D'	5·2	9·3	6·3	6·5	8·6	18·4	3·2	14·6	13·8
Mdn. D'	3·5	5·5	4·0	2·0	5·0	11·0	2·0	5·5	7·0
σ of D'	5·0	9·3	6·4	11·0	10·3	17·4	4·3	31·7	19·8
Mean S'	8·8	3·4	1·8	8·5	5·8	3·1	5·0	4·4	5·8
Mdn. S'	7·7	1·6	1·5	4·2	3·8	1·5	3·8	3·1	2·1
σ of S'	6·7	4·4	1·5	8·8	6·7	3·4	4·1	3·9	8·5
				Experiment II					
Mean D'	5·9	5·2	12·3	4·0	9·6	15·4	3·2	13·7	14·2
Mdn. D'	5·0	2·8	4·5	2·2	3·0	11·0	1·8	8·5	8·0
σ of D'	4·9	5·2	9·3	5·6	15·4	17·6	4·1	26·2	14·0
Mean S'	16·3	6·5	7·5	16·3	9·7	10·7	9·9	17·7	11·6
Mdn. S'	11·0	3·0	2·0	7·0	3·0	3·0	5·0	6·0	2·5
σ of S'	15·0	8·8	12·8	23·8	15·8	15·0	12·2	28·9	21·2

In Experiment I, perceived width was measured kinesthetically. In Experiment II, perceived width was measured by verbal reports. In both experiments perceived distance was indicated by verbal reports. All D' values are in feet. All S' values are in inches.

since some of the distributions clearly are skewed. Because the distributions tend to be skewed, non-parametric tests were used to determine the significance of differences throughout this study. The Kruskal–Wallis one-way analysis of variance by ranks (SIEGEL, 1956), taking ties into consideration, was used to analyze the data of Table 1. Of particular interest are the results from the first presentations, since only these results are relevant to the problem of the direct perception of retinal size. The D' values obtained from the different retinal sizes of the rectangle on the first presentations were not significantly different at the 0·05 level ($H=2·69$, $df=2$). It will be noted that the increase in mean D' that occurred when the 128′ rather than the 428′ visual angle was used in the first presentations is reduced when medians rather than means are considered, and that the rectangle with the smallest retinal size did not result in the largest mean or median D'. The S' values obtained from the first presentations of the different sizes of the rectangle are significantly different beyond the 0·01 level as a function of the retinal size of the rectangles ($H=17·78$, $df=2$). This trend is reflected clearly in both the mean and median values of S'. The results from the first presentations show that, although no consistent differences in perceived distance occurred as a consequence of differences in visual angle, perceived size increased systematically with increasing visual angle.

The D' results from the second and third presentations, unlike those from the first presentations, increased significantly (at the 0·01 level) as the retinal size (visual angle) decreased (H=14·29 and 13·48 respectively, $df=2$). These D' results from successive presentations involve the relative size cue occurring between successive presentations of the different retinal sizes and the changes in D' are to be expected from this cue system. It is interesting to note that the average (or median) values of perceived width S' are not as different as a function of retinal size (θ) in the second presentations as in the first presentations and in the third presentations these differences have almost disappeared.

It can be concluded from the results of Experiment I that, for geometric (non-representational) objects presented under reduced conditions of observation, the perceived sizes of the first presentations of the objects tended to increase with an increase in visual angle without a concomittant tendency for the objects to decrease in perceived distance. For subsequent presentations the relation between perceived size and retinal size (visual angle) tended to disappear and the usual inverse relation between perceived distance and retinal size appeared.

Pearson product–moment correlations were obtained between S' and D' for each of the values of θ in the first presentations. These correlations are $-0{\cdot}03$, $+0{\cdot}54$, and $+0{\cdot}76$ for the 64′, 128′, and 428′ visual angles, respectively. Only the correlations for the medium and large sizes are significant at the 0·05 level ($df=18$). The implication of these data for the problem of the direct perception of retinal size will be considered together with the data from Experiment II.

EXPERIMENT II

Experiment II was identical to Experiment I with the following exceptions: (1) Ninety observers were used of which 30 observers first viewed the large size of rectangle, 30 different observers first viewed the medium size, and 30 different observers first viewed the small size. (2) For each observer, instead of the kinesthetic adjustment, perceived width was measured by a single verbal report (expressed in feet or inches or in some combination of both) of the apparent width of each size of rectangle, following each report of distance. (3) The observers remained in the totally dark observation booth for 5 min before being presented with any of the rectangles.

The results from Experiment II are shown in the lower portion of Table 1. In agreement with Experiment I, the S' results from the first presentations of Experiment II differ significantly at the 0·01 level as a function of the visual angular size of the rectangle ($H=20{\cdot}75$, $df=2$). The increase in S' as a function of increased visual angle occurred only for the 428′ as compared with each of the two smaller sizes. Unlike Experiment I, D' in Experiment II, changed significantly as a function of visual angle at the 0·01 level ($H=10{\cdot}29$, $df=2$). It will be noted, however, that this result can be attributed to the small visual angle (64′) condition only and is reflected only in the mean not median differences. Since the difference in perceived size (S') occurred with the largest angular size and the difference in perceived distance (D') occurred with the smallest angular size, it is unlikely that the variation in S' can be explained by the change in D'.

The same pattern of results appear in Experiment II as in Experiment I for the second and third presentations. As in Experiment I, for the second and third presentations, the D' values differ significantly (at the 0·01 level) as a function of the visual angle ($H=22{\cdot}18$ and 29·65, $df=2$) and the S' differences tend to disappear.

The Pearson product correlation coefficients between S' and D' for the first presentations are $+0{\cdot}62$, $+0{\cdot}43$, and $+0{\cdot}67$ for the small, medium, and large sizes, respectively, with each of these values significant at least at the 0·05 level of confidence ($df=28$). The correlation coefficients for the first presentations in both Experiments I and II tend to be positive in agreement with the size-distance invariance hypothesis. In several (but not all) instances, however, the larger value of the positive correlations are determined by the data from one or two observers.

EXPERIMENT III

According to the results from Experiments I and II, the perceived width of the rectangles in the first presentations was greater for the larger sizes of rectangle. But, the perceived distances (D') of the different sizes of rectangle in the first presentations either were not significantly different or occurred between retinal sizes that did not result in different values of S'. It is tempting, therefore, to conclude from the results of the first presentations that the observers were able to perceive directly an object size proportional to the size of the retinal image. However, before this conclusion can be justified, it must be demonstrated that the different perceived sizes were not the result of D' being essentially the same for the first presentations. In other words, it must be demonstrated that in the first presentations there was no tendency for objects under the reduced conditions of observation to be perceived at some specific distance which was the same or approximately the same for the different values of angular size. The purpose of Experiments III and IV was to test the hypothesis that the observer, in the absence of distance information, will perceive an object at some specific distance. This tendency will be called the "specific distance tendency".

Since the conditions upon which the specific distance tendency would depend are unknown, it is not possible to demonstrate its presence by causing it to vary as a function of changes in stimulus conditions. Rather the existence of the tendency was investigated by measuring whether a perceived distance, as determined by some distance factor in one presentation, could be modified in a subsequent presentation in which the perceived distance was determined by the specific distance tendency. In other words, on a first presentation an experimental object was made to appear at a distance different from that expected from the specific distance tendency. The question was whether on a subsequent presentation, in which only the specific distance tendency was present, the object would appear at a new distance as determined by this tendency. For this reason, in Experiments III and IV, experimental groups of observers were first presented with a visual alley containing a floor and walls in which a vertical rectangle appeared suspended. Under these conditions, the most distant portions of the alley are directionally closest to the rectangle and the rectangle will appear to be located in depth near the more distant portions of the visual alley as a consequence of the equidistance tendency (Gogel, 1965; 1969). Following the presentation of the rectangle in the visual alley, the rectangle was presented alone (under reduced conditions) to the same observer. If the specific distance tendency did not exist, the observer would have no reason to change his judgment of the distance of the rectangle from himself, as a consequence of the change from the visual alley to the reduced condition. If the specific distance tendency exists and, as suggested by the results of Experiments I and II, if this tendency is such as to perceptually localize the rectangle close to the observer, it would be expected that the reported distance of the rectangle would be less in the second than in the first presentation in Experiments III and IV. The results from the experimental groups can be compared with the results from control groups in which the order of presenting the visual alley and the reduced conditions were reversed.

Apparatus

The floor of the visual alley was approximately 3 ft wide, with two center white stripes and with a black strip on the left and right. Each of the stripes were 9 in. wide and extended the length of the alley floor from a position near the observer to a black curtain forming the back of the alley at a distance of 19 ft from the observer. White cloth formed the left and right side of the alley. The alley was illuminated by evenly spaced lights on the ceiling. Five familiar objects were placed at different distances from the observer along the floor of the alley. These were a box of cough drops at 4 ft, a bottle of ink at 7 ft, a coffee cup at 11 ft, a stapler at 15 ft, and a pencil sharpener at 18 ft. Two sizes of rectangle of the same shape as in Experiments I and II were used. The width of the large and small sizes of the rectangle subtended visual angles of 320′ and 64′, respectively. The rectangles presented in Experiment III were produced on a rear projection screen using the same point source system used in the two previous experiments. The screen was located at a distance of 10·6 ft from the observer. The luminous rectangle on the screen was viewed by means of a partly transmitting, partly reflecting mirror located directly in front of the observer. This mirror permitted the alley and luminous rectangle to be viewed simultaneously when required by the experiment. The rectangle appeared to be suspended above the alley with the visual direction to the bottom of the rectangle 5 and 19 in above the floor of the far end of the alley for the large and small rectangle respectively. Three conditions could be presented. In the "alley" condition both the lights above the alley and the projection system were turned on so that the observer perceived the alley and the rectangle simultaneously. In the "reduced" condition, the alley was not visible and the luminous rectangle appeared in an otherwise totally dark visual field. In the "calibration" condition the rectangle was not visible, the observer perceived only the alley containing the familiar objects and indicated by verbal reports the perceived distances of these objects from his eye. The purpose of the "calibration" condition was to calibrate the verbal reports of distance (GOGEL, 1968). Since adequate cues to perceived distance were present in the alley, it was assumed that errors in judging the distances of the familiar objects located on the alley floor could be attributed to errors involved in applying a "foot ruler" to the estimation of distance. Thus, the results from the "calibration" condition could be used to correct the distance estimates to the rectangle obtained in the two other conditions so as to convert reported distance to perceived distance. All observations in all conditions were made by the observer with his right eye only. The luminance of the rectangles and the average luminance of the alley (approximately) in both Experiments III and IV were 0·4 ft-L.

Procedure

One hundred observers were used in Experiment III. The calibration condition was always presented last so that the judgments made in the other conditions would not be affected by the calibration. Fifty observers were presented first with the alley condition followed by the reduced condition. For the other fifty observers, the order of the alley and reduced conditions was reversed. Of the fifty observers who were presented with a particular order, 25 were presented with the small (64′) rectangle only and the remaining 25 were presented with the large (320′) rectangle only. Both perceived size and perceived distance were measured by verbal reports expressed in feet and inches. A single verbal report of distance for a rectangle presented in the reduced or alley condition was always followed by a single verbal report of width for that same rectangle in the same condition. Before being presented with any visual stimuli, the observer remained in the totally dark observation booth for 5 min.

Results

The results from Experiment III are shown in the upper portion of Table 2. Throughout this and the next experiment the Wilcoxon test and the Mann–Whitney U test were used

TABLE 2. PERCEIVED DISTANCE D' AND PERCEIVED WIDTH S' OF TWO RETINAL SIZES OF A RECTANGLE PRESENTED EITHER ALONE (REDUCED CONDITION) OR SIMULTANEOUSLY WITH A VISUAL ALLEY (ALLEY CONDITION)

	Large rectangle (320 min)				Small rectangle (64 min)			
	First presentation		Second presentation		First presentation		Second presentation	
	Reduced	Alley	Reduced	Alley	Reduced	Alley	Reduced	Alley
	Experiment III							
Mean D'	5·9	13·1	7·8	11·5	12·5	12·5	8·6	11·8
Mdn. D'	5·0	10·0	6·0	10·0	8·0	12·0	8·0	12·0
σ of D'	4·8	5·3	6·4	4·6	19·4	4·1	6·8	4·7
Mean S'	20·8	28·6	21·5	22·0	9·5	7·0	4·4	5·5
Mdn. S'	10·0	30·0	24·0	24·0	2·0	5·0	4·0	4·0
σ of S'	46·3	11·7	16·3	7·6	19·0	6·6	2·5	4·4
	Experiment IV							
Mean D'	8·1	10·2	9·6	11·7	11·7	11·6	9·3	12·4
Mdn. D'	8·0	10·0	8·0	10·0	10·0	10·0	5·0	12·0
σ of D'	6·3	4·9	8·4	5·8	11·6	5·6	11·3	5·5
Mean S'	16·4	24·1	18·6	24·8	8·4	6·1	8·5	6·0
Mdn. S'	12·0	24·0	18·0	24·0	4·0	5·0	5·0	5·0
σ of S'	13·1	8·4	15·1	13·1	10·3	4·3	11·2	2·9

In Experiments III and IV the rectangles were physically at 10·6 ft and 21·2 ft respectively. All D' values are in feet. All S' values are in inches.

to test the significance of differences between correlated and uncorrelated distributions, respectively. The two columns in the upper portion of Table 2, in which the reduced situation was presented first, represent the results from the two independent groups of 25 observers each, with one of the groups presented with the large rectangle and the other with the small rectangle. From the results of Experiments I and II, it would be expected that, under these conditions, the small rectangle would have resulted in smaller values of S', but not necessarily larger values of D', than the large rectangle. The difference between the perceived sizes (S') from the "*first presentations, reduced*" of the large and small rectangles was significant at the 0·01 level of confidence ($Z=2·68$). The difference between the perceived distances (D') from the *first presentations, reduced* of the small and large rectangle was not significant at the 0·05 level of confidence ($Z=1·45$). In agreement with the two previous experiments, observers who were first presented with the large rectangle under reduced conditions of observation perceived it as larger than the observers who first viewed the small rectangle under the same conditions. It is less certain that the perceived distance was the same for the two sizes of rectangles under these conditions, since the perceived distance to the small rectangle tended to be greater (but not significantly greater) than the perceived distance to the large rectangle.

The central result of Experiment III is found in the comparison of the columns labelled *first presentation, alley* and *second presentation, reduced* in Table 2 for both the large and small rectangles. These columns show the S' and D' results from presenting the alley condition first followed by the reduced condition for the same observers and same size of rectangle. It will be noted for both the large and small rectangle that D' is less in the reduced than in the corresponding alley condition. Each of these differences in D' (corresponding to mean differences of 13·1–7·8 and 12·5–8·6) was significant at the 0·01 level using the Wilcoxon test ($T=22$, $N=22$ and $T=35$, $N=22$). The differences between the value of S' (corresponding to mean differences of 28·6–21·5 and 7·0–4·4) were significant at the 0·01 level ($T=36{\cdot}5$, $N=19$ and $T=25{\cdot}5$, $N=18$). The observers tended to perceive the rectangles as closer and smaller in the reduced condition after perceiving the rectangles to have a larger size and distance in the previous (alley) presentation. *This result offers support for the existence of a specific distance tendency.*

The Pearson product-moment correlation between S' and D' was calculated for each of the values of θ in the first presentation of the reduced condition. These correlations are 0·91 and 0·37, for the 64′ and 320′ visual angles, respectively, and are significant at the 0·05 level (one-tailed test, $df=23$).

The results from the calibration situation of Experiment III are shown in the upper portion of Table 3. An examination of the calibration data indicates that the relation between the verbal reports of distance and the physical distances D of the familiar objects is essentially linear. The line of best fit for this data and for the calibration data of Experiment IV is given at the bottom of the table. If it is assumed that physical distance is equal to perceived distance along the floor of the visual alley, the data of Table 3 indicates that the verbal reports of distance tended to be proportional to, but an underestimation of, perceived distance (GOGEL, 1968). If this proportionality had not occurred, the appropriateness of using the reported distances to test the applicability of equation (1) would be in doubt (GOGEL, WIST and HARKER, 1963).

TABLE 3. OBJECT DISTANCES D AND OBTAINED RESULTS IN FEET FROM THE CALIBRATION SITUATIONS OF EXPERIMENTS III AND IV*

Object	Cough drops	Ink	Cup	Stapler	Pencil sharpener
	Experiment III				
Physical distance	4·0	7·0	11·0	15·0	18·0
Average reported distance	2·0	4·3	6·7	9·6	11·6
Mdn. reported distance	2·0	4·0	6·0	8·5	10·0
σ of reported distance	1·0	1·7	2·5	3·6	4·3
	Experiment IV				
Average reported distance	1·8	4·0	6·3	8·6	10·2
Mdn. reported distance	1·5	3·5	6·0	8·0	9·5
σ of reported distance	1·1	1·9	2·8	3·7	4·3

*Least squares line of best fit:
Experiment III—verbal report of $D'=0{\cdot}68\ D\ -0{\cdot}67$ ft.
Experiment IV—verbal report of $D'=0{\cdot}59\ D\ -0{\cdot}34$ ft.

EXPERIMENT IV

In most experiments concerned with reduced conditions of observation, it is likely that some residual cues remain, such as slight cues of accommodation or accommodative-convergence to the screen at 10·6 ft in Experiment III. This problem is not avoided by using optical devices or restrictive artificial pupils, since these procedures merely result in establishing a particular accommodative state of the eye rather than eliminating all accommodative cues. Although residual cues were reduced extremely in the present study, it is possible that to the extent that residual cues were present, no matter how slight, they served as the determiners of the specific distance tendency. Before the existence of a specific distance tendency can be accepted as a general phenomenon it must be demonstrated that slight residual cues could not have accounted for the perceived distances usually obtained in these experiments. The average of the two median values of D' of Experiment III from the first presentations of the reduced condition can be taken as most nearly representing the specific distance tendency for Experiment III. This value of 6·5 must, however, be corrected by the calibration curve derived from Table 3 for this experiment. The resulting value of 10·5 ft is very similar to the 10·6 ft distance of the projection screen. In Experiments I and II, calibration equations were not determined. If the calibration equation determined in Experiment III is applied to the average median value from the first presentations of the rectangles in Experiments I and II, the results are 7·31 and 7·01 ft, respectively. Since the physical distance of the screen in Experiments I and II was 13 ft from the observer, it is unlikely that residual cues determined the perceived distances in these experiments. However, to test the possibility that the specific distance tendency was determined by residual cues, Experiment IV was designed. In Experiment IV, the physical position of the rectangles was always at a distance of 21·2 ft from the observer instead of the 10·6 ft used in Experiment III.

Apparatus

The apparatus for Experiment IV was identical to that of Experiment III except that the rear projection screen was not used. Instead, rectangles of the same retinal sizes and luminance as those used in Experiment III were produced by a large fluorescent light box and one of two sizes of aperture located on the light box at a distance of 21·2 ft from the observer. The light box was physically located to the left of the visual alley and was viewed by first surface mirrors so as to appear to the observer in the straight ahead position.

Procedure

One hundred observers were used in Experiment IV. The procedure including the instructions was identical to that used in Experiment III.

Results

A summary of the results of Experiment IV is shown in the lower portion of Table 2. It will be noted that the results tend to parallel those from Experiment III. Again, the perceived size of the small rectangle, when first presented under reduced conditions, was significantly smaller ($Z=2·73$) than the perceived size of the large rectangle under the same conditions at the 0·01 level. Although the difference in D' between the small and large rectangle under the first presentation, reduced conditions suggests that the smaller rectangle was perceptually more distant, this difference is not significant. The average (and median) perceived distances for both the large and small rectangles from the first presentations of the alley were greater than those obtained from the immediately following reduced condition with no alley present. Using the Wilcoxon test, this difference was significant (with a one-tailed test) at the 0·05 level for the small but not the large rectangle ($Z=1·87$ and 1·06 respectively). *These changes in D' again suggest that a specific distance tendency exists.* Only in the case of the large rectangle was the change in perceived size significant (at the 0·05 level) between the first presentation, alley condition and the second presentation, reduced condition ($T = 32$, $N = 19$).

The Pearson product–moment correlations between S' and D' in the first presentations of the reduced conditions were 0·12 and 0·70 for the 64′ and 320′ visual angles, respectively. Only the larger of these correlations is significant at the 0·05 level ($df=28$).

The results from the first presentations of Experiment IV, like those from Experiments I, II, and III, support the conclusion that, under reduced conditions of observation, objects have a perceived size that is proportional to their retinal size, even though the perceived distance of the objects of different retinal size can remain invariant. The results from Experiment IV, like those from Experiment III, suggest that the reason for the proportionality of perceived and retinal size is that, under reduced conditions of observation, a tendency is present to perceive an object as being at a specific distance and that this specific distance is independent, in general, of retinal size. Finally, Experiment IV provides only limited support for the hypothesis that the specific distance tendency in the present study was determined by residual cues of distance. In Experiment IV the physical distance of the rectangles was twice as great as in Experiment III. Nevertheless, the average values of D' in these two experiments, from the first presentations of the reduced conditions, are similar, with the median values of D' from these conditions, however, being larger in Experiment IV than in Experiment III. Using the Mann–Whitney U test, the differences between the D' results from the two experiments for the first presentations, reduced conditions were not significant for either the large or the small rectangle ($Z = 1{\cdot}36$ and $0{\cdot}72$ respectively). Probably the specific distance tendency can be somewhat modified by, but is not determined by, residual distance cues.

DISCUSSION

In Experiments I and II different retinal sizes of rectangles were first presented to different groups of *O*s followed by the successive presentation of the different retinal sizes to the same groups. It is clear that the responses from the first and from subsequent presentations are quite different. Although there seemed to be a tendency in the first presentations for smaller values of θ to result in larger values of D', this tendency did not always occur and was not statistically significant except in one instance in Experiment II. This lack of clear average (or median) differences in perceived distance from the first presentations is to be contrasted with the distance responses on the second and third presentations. With these subsequent presentations D' is clearly an inverse function of θ. The reverse result occurred, however, when size responses are considered. In this case S' was a direct function of θ in the first presentations, but in the second and third presentations S' tended to become increasingly independent of θ. Increases in retinal size resulted mainly in increases in perceived size in the first presentations and mainly in decreases in perceived distance in the subsequent presentations. For this reason, the results from the first and subsequent presentations must be considered separately.

FIRST PRESENTATIONS

Relation between S'/θ and D'

The results from the first presentations in the present study are consistent with the expression of the size-distance invariance hypothesis in which perceived size S' per unit of retinal size θ is a monotonic increasing function of perceived distance D'. This is indicated by Fig. 1 in which the data points show the relation between S'/θ and D' as determined from the first presentations, reduced conditions, using the data from all four experiments of this study. Each data point in Fig. 1 is the median obtained value of S'/θ (expressed in cm per rad) plotted against the median obtained value of D' (expressed in cm), with each point involving a different group of observers. Medians are used rather than means since medians are less affected than are means by unusually large reports from a few observers. The data points labeled 1, 2, and 3 are from Experiment I, points 4, 5, and 6

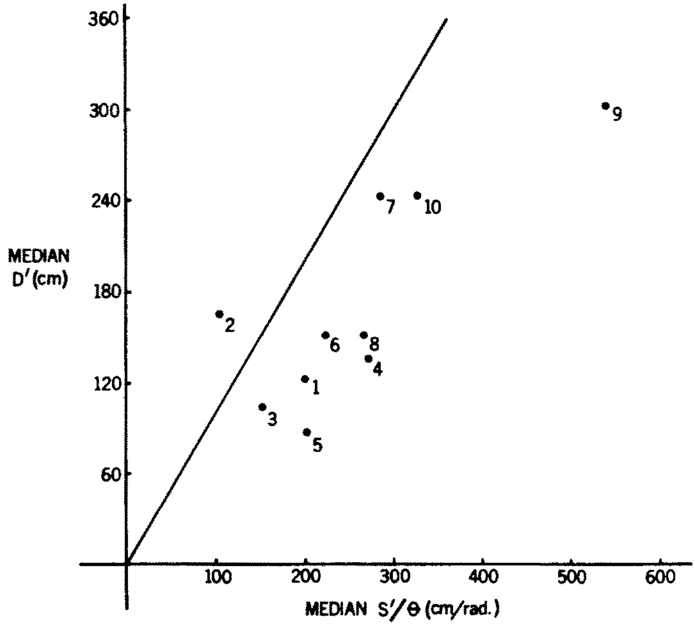

FIG. 1. Median values of perceived size (S') per unit of visual angle (θ) from the first presentations, as a function of the perceived distances (D') of the rectangles. The solid line represents the results expected from equation (1) if $K=1$.

are from Experiment II, points 7 and 8 are from Experiment III, and points 9 and 10 are from Experiment IV.

As shown by Fig. 1, on the first presentations, as the rectangles appeared at different distances in the different experiments, their S'/θ values tended to vary proportionally. A Pearson product-moment correlation coefficient was computed from the data points of Fig. 1. This correlation (0·79) is significant at the 0·01 level ($df=8$). Figure 1 supports equation (1), even though different groups of observers were used for the different data points and even though cues to both size and distance were very reduced. This support of equation (1) is indicated also by the general tendency throughout this study for S' and D' to be positively correlated between observers for a constant value of θ. The size-distance invariance hypothesis seems to hold for conditions in which cues to size and distance are severely reduced, and therefore, a postulation of the direct perception of retinal size under these conditions is unnecessary.

It is not clear why D', on the first presentations, as shown by Fig. 1, was sometimes quite different between experiments, with different groups of observers for the same values of θ. The spread of the data points in Fig. 1 must be regarded as a limitation on the effectiveness of the specific distance tendency, since this tendency should have resulted in a constant D'. The specific distance tendency, therefore, should be considered to be a general tendency upon which other effects are superimposed, including possible differences between groups.

The solid line in Fig. 1 is the condition in which K in equation (1) is unity. This is the relationship necessary for perceptual veridicality in the sense that only when K is unity will perceived size be veridical if perceived distance is veridical and vice-versa. But, it can be reasoned that the median D' values of Fig. 1 should be corrected by calibration functions similar to those indicated in Table 3, in order for these D' values to represent perceived instead of merely reported distance. For this correction the physical distance D in the calibration equation is assumed to be equal to perceived distance D'. Since calibration data were not obtained for all of the experiments represented in Fig. 1, this correction cannot be made. It will be noted, however, that according to the calibration data of Table 3, physical distance in a full cue situation i.e. perceived distance, tends to be underestimated. This underestimation is the usual result in calibration situations of this type (GOGEL, HARTMAN and HARKER, 1957; GOGEL, 1968). The expected consequence of applying the appropriate calibration data to Fig. 1 would be to shift the majority of the data points in the direction of the solid line, i.e. toward $K=1$. If it can be assumed that the resulting corrected data would fall along the solid line in Fig. 1, an interesting interpretation of Fig. 1 is possible. If an object is physically located at the distance specified by the specific distance tendency, its distance, by definition, will be correctly perceived. If $K=1$, it also follows that the size of the object at the distance defined by the specific distance tendency will be correctly perceived. In other words, if it can be assumed that the application of calibration data would have resulted in a slope of unity in Fig. 1, it would follow that an object placed at the distance defined by the specific distance tendency for the particular observer would be correctly perceived in both size and distance by that observer. This distance, at which size and distance are correctly perceived, can be called the distance of correct (true) perception D_T. The present study at least is suggestive of the hypothesis that the distance indicated by the specific distance tendency is also the distance of correct perception (D_T) for both perceived size and perceived distance.

Applications of the specific distance tendency

It is possible that the value of the specific distance tendency or of D_T will differ depending upon the assumptions that the observer brings to the particular situation. The set of the observer might vary for reasons not presently understood so that on different occasions perceived distance resulting from the specific distance tendency might be 25 ft or 100 ft, etc. Certainly, this possibility cannot be dismissed from the data of the present study and indeed as indicated by the results, the value of the specific distance tendency or of D_T can be expected to vary considerably between groups or between experiments. It is interesting to note, however, that distances of correct perception have been identified in other studies for other conditions. In binocular vision, using only the binocular disparity cue, a distance can be inferred at which a depth interval is perceived correctly with respect to an adjacent frontal extent (GOGEL, 1958) or with respect to a distance from the observer (FOLEY, 1967). When the function relating convergence and perceived extent from binocular disparity is considered, these distances of correct perception seem to be of the same general order of magnitude as those suggested by the present study. It can be postulated, therefore, that at a distance somewhere within 3–12 ft, with binocular disparity the only depth cue present, objects will tend to be perceived correctly in three dimensional shape, depth, and distance from the observer.

The significance of the specific distance tendency can be considered more generally. Suppose that two rectangles of different retinal size are presented simultaneously and are viewed monocularly under reduced conditions of observation. The difference in the retinal sizes of the two rectangles would result in the rectangles appearing at different distances, but their perceived positions from the observer would remain undetermined except for the possible effect of the specific distance tendency. In this case, which of the rectangles would appear at the distance indicated by the specific distance tendency? Clearly, since the rectangles are perceptually located at different distances by the relative size cue, both cannot appear simultaneously at the distance of the specific distance tendency. Perhaps the center of the apparent depth interval between the two rectangles, or perhaps the apparently more distant rectangle would appear at D_T. In general, it is likely that, in the absence of egocentric cues to distance, a visual display with good cues to relative distance will have some systematic position with respect to the distance defined by the specific distance tendency or D_T. If this occurs, it follows, that the specific distance tendency would provide an absolute metric for both size and distance perceptions within the display. In other words, although the relative size cue could specify, for example, that one rectangle was twice the distance of the other, the specific distance tendency would be necessary in order to permit the observer to state, for example, that the distance between the rectangles was 5 ft and that each rectangle was, for example, 4 in. wide. It will be noted in the present experiments that the observers were able to make such metric judgments of size and distance with successive as well as with the first presentations. It seems reasonable to suggest that the metric character of these responses were possible as a consequence of the specific distance tendency.

The specific distance tendency, found in the present research, using monocular observation, also might introduce a metric into binocular visual space. For example, it would provide an explanation for the ability of the binocular observer, using stereoscopic cues, to judge a depth interval relative to an egocentric distance from himself, or to judge two egocentric distances with respect to each other. It is clear that these kinds of judgments can occur (FOLEY, 1968; NISHIKAWA, 1967; SHIPLEY, 1957), but it is less clear how they are mediated. It is reasonable to expect that a binocular disparity defined as a difference in horizontal extent on the two eyes would indicate that one object is more distant than the other. But it is more difficult to understand how such limited information could support egocentric comparisons unless information were present to provide at least a relative yardstick. If a specific distance tendency exists with monocular observation, it is possible that it could act in binocular observation to relate egocentric and exocentric perceptions from stereoscopic cues. The suggestion is that perceptions determined by the distance of correct perception or the specific distance tendency represent a basic perceptual structure that asserts itself whenever empirical information is reduced, as occurs, for example, in egocentric perceptions using stereoscopic cues. Clearly, this suggestion requires further examination. What is needed is a study of observer communalities occurring in perceptual judgments of size and distance from monocular and from binocular observation with the objective of identifying the perceptual processes common to these two conditions of observation. An implication of the concept of the specific distance tendency is that metric perceptions, for example, perceptions capable of being expressed in feet or inches, are possible even with reduced conditions of observation. Although, with visual fields extended in depth, such perceptions would tend to be veridical only at the distance of correct perception, the specific distance tendency would provide a ruler that possibly would permit metric perceptions to occur throughout the visual field.

The present research suggests that the specific distance tendency cannot be accounted for totally by the presence of extraneous cues or by knowledge on the part of the observer of the size of the room within which the observations occur. What is the basis of the specific distance tendency? Although this question cannot be answered at present, there is additional evidence indicating a behavioral preference for a distance of the general magnitude suggested by the specific distance tendency. This evidence is concerned particularly with the resting state of accommodation and has been reviewed by SCHOBER (1954). Schober asserts that the existance of night myopia, the distance of maximum visual acuity, the tendency for an observer to prefer a negative accommodation in optical instruments, and the form of the horopter indicates that the resting position for the accommodation of the eyes is located between the near and far point. He suggests that this reflects the behavioral importance of objects lying between 0·5 and 2 m from the observer. Since these distances approximate those of the specific distance tendency, it can be postulated that in the absence of other determining visual information the processes of accommodation, perceived egocentric distance and possibly other visual events tend to adjust for maximum acuity and veridicality at this distance. In this case, neither the accommodative adjustment nor the specific distance tendency determine each other but both are the product of the significance of this distance for behavior.

SECOND AND THIRD PRESENTATIONS

The results from the first presentations shown in Fig. 1 provide strong confirmation that the perception of size with totally reduced conditions of observation is not independent of perceived distance. Indeed, under these conditions, the size-distance invariance hypothesis seems to hold remarkably well. In general, the judgments of size and distance from the second and third presentation in Table 1, also are in agreement with the size-distance invariance hypothesis, but, as was indicated above, the process underlying these judgments is quite different from that involved in the first presentations. When the observer is presented successively with different retinal sizes of rectangles of the same shape, it is as though the rectangles are perceived to be the same size and the difference in their retinal size is perceived as a difference in distance. The identical shape of the rectangles in the successive presentations seems to convey the information that the successively presented rectangles are the same size. As a consequence of this, the perceived size of a second presentation is less determined by its particular retinal size via the specific distance tendency and is more determined by the perceived size of the prior presentation. When presented with effective information (in this case the identical shape of the rectangles in the successive presentations), observers will relinquish a perception of size determined by retinal size and the specific distance tendency and will perceive the rectangle to have a size in accord with the information. This is in agreement with the results from a study by ONO (1966) in which, under non-reduced conditions, observers learned to respond with the correct distal size more readily than with the correct proximal size. It is to be expected that for full cue conditions the perceived size will not be determined as a result of retinal size and the specific distance tendency. Probably as distance cues become less effective, for example, when terrain cues are absent or when viewing through restrictive apertures, the effectiveness of the specific distance tendency is increased, and as a result the perception of size tends increasingly to be proportional to retinal size. Possibly the specific distance tendency, like the equidistance tendency, is a kind of visual organization which becomes increasingly influential in determining perceived extent as the cues usually present for these perceptions become increasingly reduced. The results from the present study suggest the operation of two perceptual processes. One process concerned with egocentric localization occurs in the absence of cues to egocentric distance and is determined by retinal size and the specific distance tendency. The second process concerned with exocentric, relational perceptions increasingly dominates the perception of size and distance with increasing amounts of either simultaneous or successive information.

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Abstract—This study examines the interpretation that under reduced conditions of observation the perceived size of an object is the result of a direct response to retinal size. In opposition to this interpretation is the size-distance invariance hypothesis stating that a perceived size results from a retinal size only when an appropriate perceived distance is also present. Four experiments were conducted. The first two experiments indicate that in the absence of distance cues, perceived size is proportional to retinal size. The last two experiments suggest that this result is a consequence of the tendency, under reduced conditions, to perceive the objects at a common (specific) distance. The results support the size-distance invariance hypothesis and are in opposition to the direct perception of retinal size. The possible significance of the specific distance tendency is discussed for binocular as well as monocular conditions of observation.

Résumé—On soumet a examen l'interprétation selon laquelle la dimension perçue d'un objet résulte d'une réponse directe à la dimension rétinienne, sous certaines conditions réduites d'observation. Contrairement à cette interprétation, l'hypothèse d'invariance de la taille avec la distance suppose que la dimension perçue ne résulte de la dimension rétinienne que si une perception appropriée de la distance est également présente. On réalise quatre expériences. Les deux premières indiquent qu'en l'absence de données sur la distance, la dimension perçue est proportionnelle à la dimension rétinienne. Les deux dernières expériences suggèrent que ce résultat est une conséquence, sous conditions réduites, de la tendance à percevoir les objets à une distance constante (spécifique). Ces résultats confirment l'hypothèse d'invariance taille-distance et sont en opposition avec une perception directe de la dimension rétinienne. On discute la signification possible de cette tendance à une distance spécifique pour des conditions d'observation binoculaire ainsi que monoculaire.

Zusammenfassung—In dieser Untersuchung prüft man die Meinung, ob sich die Sehgrösse eines Gegenstandes unter verminderten Beobachtungszusbedingungen direkt aus einer Antwort auf Netzhautgrösse ergibt. Die Grössendistanzhypothese steht im Widerspruch zu dieser Erklärung und besagt, dass sich die Sehgrösse nur in Gegenwart der entsprechenden Sehentfernung aus der Netzhautgrösse ergibt. Vier Versuche wurden unternommen. Die zwei ersten zeigen an, dass die Sehgrösse zur Netzhautgrösse proportionell ist, falls es keine Entfernungsangaben gibit. Die zwei letzteren Versuche deuten aber an, dass sich dies aus der Tendenz Gegenstände unter verminderten Beobachtungszustände an einer gemeinsamen (spezifischen) Entfernung in Wahrzunnehmen ergibt. Die Ergebnisse stützen die Hypothese der Grössen-Distanz-Beständigkeit und widersprechen einer direkten Netzhautwahrnehmung. Die mögliche Bedeutung der zu einer spezifischen Entfernung für sowohl beidäugige als auch einäugige Beobachtungsbedingungen wird erörfert.

Резюме — Предметом исследования послужила гипотеза о прямой зависимости воспринимаемого размера объекта от размера ретинального изображения при органичении условий наблюдения. Этой гипотезе противопоставляют гипотезу о константности отношения размера к расстоянию, в соответствии с которой видимый размер зависит от размеров ретинального изображения только в тех случаях, когда соответствующим образом воспринимается и расстояние. Проведено 4 эксперимента. Первые два опыта показывают, что в отсутствие факторов восприятия удаленности воспринимаемый размер пропорционален ретинальному размеру. Последние два опыта позволяют трактовать этот результат как следствие тенденции к восприятию объектов (при ограниченных условиях наблюдения) на одном и том же определенном расстоянии. Полученные результаты поддерживают гипотезу инвариантности отношения размера к расстоянию и противоречат гипотезе о прямой зависимости восприятия размера от ретинального размера. Обсуждается возможное значение тенденции к восприятию определенного расстояния для условий как монокулярного, так и бинокулярного наблюдения.