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# DETERMINANTS OF APPARENT VISUAL SIZE WITH DISTANCE VARIANT

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The size of the retinal image is a peripheral determinant of visual size. Presumably, if all other determinants were constant, perceived size would vary directly with the visual angle, which might even be used then as a measure of apparent size. It has been known for a long time, however—since Fechner[1] and Hering,[2] at any rate—that the visual angle does not provide a consistent measure of perceived size when the distance from *O* to the stimulus-object is varied. Martius' experiment[3] in 1889 demonstrated that the apparent size of objects may change scarcely at all when distance changes, and nowadays it is customary to use the term 'size constancy' as a reminder that, when perceived size is constant, the visual angle sometimes is not.[4]

Ordinarily, of course, size is not constant in spite of distance. Even the philosophers of the eighteenth century remarked that two parallel rows of trees appear to converge as one views the vista between the rows, and they attributed the convergence to the law of the visual angle and the underestimation of the greater distances.[5] To get things started toward a solution of this problem, Hillebrand[6] and others worked out the form of the curve that the walls of a short, narrow alley should have in order to appear equally separated at every distance;[7] these studies were factual in emphasis. Recently, Thouless[8] has conceived of the organism as regressing in perception from a proximal perceptual datum (the retinal image) toward a more remote one (the real object), so that actual perception can be regarded as

* Accepted for publication April 26, 1940.

[1] G. T. Fechner, *Elemente der Psychophysik,* 1860, II, 311-313.

[2] E. Hering, *Beiträge zur Physiologie,* I, 1861, 13-16.

[3] G. Martius, Ueber die scheinbare Grösse der Gegenstände und ihre Beziehung zur Grösse der Netzhautbilder, *Philos. Stud.,* 5, 1889, 601-617.

[4] Cf. K. Koffka, *Principles of Gestalt Psychology,* 1935, 87-97, 235-240.

[5] Cf. J. Priestley, *The History and Present State of Discoveries Relating to Vision, Light and Colours,* 1772, 700-704; see also W. Porterfield, *A Treatise on the Eye,* 1759, II, 381-384.

[6] F. Hillebrand, Theorie der scheinbaren Grösse bei binocularen Sehen, *Denkschr. d. kais. Akad. d. Wiss. zu Wein,* math.-nat. Kl., 72, 1902, 255-307.

[7] E.g., W. Blumenfeld, Untersuchungen über die scheinbare Grösse in Sehraume, *Zsch. f. Psychol.,* 65, 1913, 241-404, who also gives an excellent history of this problem, 243-274.

[8] R. H. Thouless, Phenomenal regression to the real object, *Brit. J. Psychol.,* 21, 1931, 339-359; 22, 1931, 1-30.

a compromise between the proximal datum and objective constancy. Brunswik[9] has stressed this compromise in his concept of an intermediate perceptual object, the *Zwischengegenstand,* and his associate Holaday[10] has shown the properties of the *Zwischengegenstand* to depend upon a variety of perceptual data.

*Size constancy* is thus an hyperbole, except as the description of a limiting case. It is not a general rule. Only at times does the organism succeed in seeing an object with no change of size at all when distance is altered. On the other hand, these remarks apply with equal force to the *law of the visual angle,* the relation which prompted Fechner and Hering to make their original observations on the relation of size to distance. This law, too, is a special case. Let us scrutinize these cases.

Accommodated objects which subtend equal visual angles are equal in apparent size. That is the law of the visual angle. If the angle $\Theta_s$, subtended by a standard stimulus, is equal to the angle $\Theta_c$, subtended by a comparison stimulus, then

$$\tan \Theta_c = \tan \Theta_s \quad \text{[A]}$$

and

$$S_c = (D_c/D_s)S_s \quad \text{[B]}$$

where $S_c$ is the linear size of the comparison object; $S_s$, the linear size of the standard; $D_c$, the distance from $O$ to $S_c$; and $D_s$, the distance from $O$ to the standard $S_s$. The size of the comparison stimulus (= apparent size of the standard) is equal to the size of the standard stimulus multiplied by the ratio of their respective distances.

The law of size constancy, on the other hand, states simply

$$S_c = S_s \quad \text{[C]}$$

where $S_c$ and $S_s$ have the same meaning as in Equation [B]. Equation [C] expresses exactly the idea communicated to many investigators by the term *size constancy.* The size of the comparison stimulus is equal to the size of the standard, irrespective of their distances from $O$.[11]

Fig. 1 shows these two relations in the way in which they are presented later in the present paper. The standard and comparison stimuli are circular in outline, uniformly and equally illuminated as $O$ sees them. The diameter of the standard stimulus subtends a constant visual angle ($\Theta_s = 1°$). $S_c$ is the size, in inches, of the comparison stimulus. $D_c$ is constant at 10 ft. $D_s$ is varied from 10 to 120 ft. The broken line drawn parallel to the axis of abscissas is the locus of all data which obey the law of the visual angle. The oblique line is the locus of values conforming to the law of size constancy.

If size constancy were a general rule, then the apparent size of the standard

[9] E. Brunswik, Die Zugänglichkeit von Gegenständen für die Wahrnehmung und deren quantitative Bestimmung, *Arch. f. d. ges. Psychol.,* 88, 1933, 377-418.

[10] B. E. Holaday, Die Grössenkonstanz der Sehdinge bei Variation der inneren und äusseren Wahrnehmungsbedingungen, *Arch. f. d. ges. Psychol.,* 88, 1933, 419-486.

[11] For the more general mathematical implications of the principles of size constancy, see E. G. Boring, Size constancy and Emmert's law, this JOURNAL, 53, 1940, 293-295.

stimulus (*i.e.* the measured size of the comparison stimulus after the subjective equation is made) should be related to $D_s$ by a function that is linear in form (slope = tan 1°). If, on the other hand, the law of the visual angle were of general validity, then $S_c$ should be constant, *i.e.* independent of distance. What actually happens is to be found for specific conditions. Systematically determined relations of this sort are wanted and wanting.[12] It must be kept in the mind that the

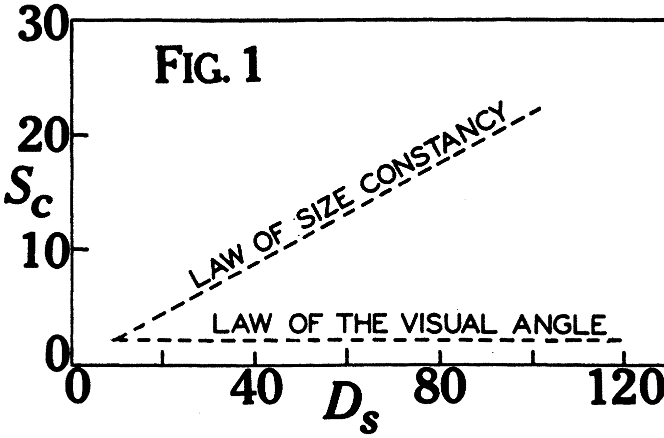



FIG. 1. LAWS OF VISUAL ANGLE AND OF SIZE CONSTANCY FOR OBJECTS OF ONE DEGREE

$S_c$ is the diameter in inches of the comparison stimulus as equated in perceived size to the diameter of a standard stimulus (angle subtended = 1°). The comparison stimulus is at a constant distance (10 ft.) from *O*. The abscissa values are the distances in feet from *O* to the standard stimulus. The oblique broken line designates the locus of all data obeying the law of size constancy. The broken line parallel to the axis of abscissas is the locus of all points obeying the law of the visual angle.

arrangement of the experiment is not in the usual form for testing size constancy, since the visual angle subtended by the standard stimulus is kept constant at 1°, so that the physical size of the standard stimulus must be increased proportionally to the distance. It is for this reason that size constancy is represented in the graphs by a straight line through the origin with slope equal to tan 1°, and the law of the visual angle is a horizontal line with slope equal to zero.

The present paper is a study of such functions, obtained under conditions in which distance is a common variant, as various effects of binocular regard, of accommodation, and of the visual frame of reference are successively eliminated. Functions relating the size of an adjusted stimulus

[12] Koffka, *op. cit.,* 1935, 91, complained of the lack of complete data for this functional relation: "Although the first experiments of this kind were made in 1889 by Götz Martius, we have to the present day no complete knowledge of the quantitative relations, the range of distances over which the investigations have been carried out being rather limited."

to the distance from $O$ to a standard stimulus subtending a constant visual angle ($\Theta_s = 1°$) were studied under four different sets of conditions: (1) binocular regard, (2) monocular regard, (3) monocular regard through an artificial pupil, and (4) monocular regard through an artificial pupil and a long black reduction tunnel stretching from $O$ to the standard stimulus, eliminating most of the visual frame of reference. The consequent data provide quantitative functions for a greater range of distances than has heretofore been available for such a variety of conditions.

## Procedure

The general plan of the experiment is sketched in Fig. 2. $O$ sat in a chair at the intersection of two long darkened corridors where he had an unobstructed view

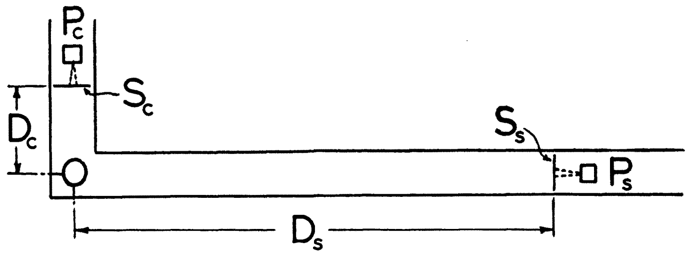



Fig. 2. Plan View of the Corridors

$S_c$ indicates the position of the comparison stimulus located at a constant distance ($D_c = 10$ ft.) from $O$. $S_s$ at a distance $D_s$ from $O$, indicates one of the positions occupied by the standard stimulus. The standard stimulus always subtended a visual angle of 1°. Distance from $O$ to the standard was varied from 10 to 120 ft. $P_c$ and $P_s$ indicate the positions of the projectors.

of a standard and a comparison stimulus. The comparison stimulus $S_c$, a uniformly illuminated circular light-image, was centered on a large white screen (8 x 8 ft.) by an ordinary projector. The screen stood at a constant distance (10 ft.) from $O$ throughout the experiment. The image on this screen could be continuously varied in size by means of an iris diaphragm conjugate with the screen. The standard stimulus $S_s$ was provided in a similar manner by another projector. The distance from the $O$ to $S_s$, however, was not constant but was systematically varied by placing the screen at various fixed distances, ranging from 10 to 120 ft. The light images for these stimuli were formed by means of circular apertures cut in thin brass plates conjugate with the standard screen. At all distances, $S_s$ subtended a constant angle (1°) at the eye of $O$. The intensity of the light (flux per unit area) from $S_s$ was constant and equal to that from $S_c$. The intensities of the light from $S_s$ and $S_c$ at the eye of $O$ were thus identical for all measurements.

$E$ regulated the size of the comparison stimulus by varying the opening of the adjustable diaphragm conjugate with $S_c$ until $O$ signified that the standard and comparison stimuli were perceived as equal in size. $O$ first fixated the standard stimulus (1°), then the comparison, looking back and forth until satisfied with the equation.

$E$ measured the diameter of $S_c$ with a meter stick. No restriction was imposed upon $O$ in regard to the length of time taken for the judgments.

All experiments were performed after midnight. Except for a few high lights, the corridors were dark. The brightest high lights were formed by light reflected from the waxed surface of the dark green tile on the floor of the corridor. Thus constellations of light images, not simply the primary images of the 'stimulus,' were located on the *O*s' retinas.

Five *O*s were employed: A. C. S. Holway, L. M. Hurvich, M. J. Zigler, A. H. Holway, and E. G. Boring. E.G.B. and M.J.Z. served as *O*s for the first complete sets of measurements. For them, 20 measurements for size were made at every

TABLE I

Binocular Observation: Apparent Size of Standard Stimulus as a Function of Its Distance

$D_s$ = distance (ft.) from $O$ to standard stimulus. At all distances, standard stimulus subtended a constant visual angle of one degree. $S_c$ = av. size (in.) of N settings of comparison stimulus, located at a distance of 10 ft. from O and equated in perceived size to standard stimulus. Intensity of light from the stimuli was constant at eye of O. m.v. = mean variation. O sat erect, facing the stimuli successively with direct binocular regard.

| | E.G.B. (N=20) | | A.C.S. (N=5) | | A.H.H. (N=10) | | L.M.H. (N=5) | | M.J.Z. (N=20) | |
|---|---|---|---|---|---|---|---|---|---|---|
| $D_s$ | $S_c$ | m.v. | $S_c$ | m.v. | $S_c$ | m.v. | $S_c$ | m.v. | $S_c$ | m.v. |
| 10 | 2.2 | 0.21 | 2.2 | 0.19 | 2.2 | 0.19 | 2.2 | 0.14 | 2.4 | 0.18 |
| 20 | 4.6 | 0.44 | 4.8 | 0.40 | 4.7 | 0.32 | | | 4.5 | 0.45 |
| 30 | | | | | | | 7.0 | 0.44 | | |
| 40 | 9.5 | 0.48 | | | 9.4 | 0.81 | | | 8.9 | 0.35 |
| 50 | | | 13.5 | 0.42 | | | 12.0 | 0.51 | | |
| 60 | 11.5 | 0.71 | 13.2 | 0.60 | 15.0 | 0.71 | | | 13.7 | 0.48 |
| 70 | | | 15.9 | 0.39 | | | 15.5 | 0.62 | 16.4 | 0.75 |
| 80 | 15.8 | 0.70 | | | 17.6 | 0.37 | | | 19.8 | 0.36 |
| 90 | | | 17.1 | 0.55 | | | | | 19.9 | 1.08 |
| 100 | 18.7 | 1.13 | | | 24.0 | 0.93 | 23.0 | 0.93 | 25.3 | 0.93 |
| 120 | 20.6 | 1.07 | 25.5 | 0.66 | 24.5 | 1.02 | 25.2 | 1.16 | 28.4 | 1.75 |

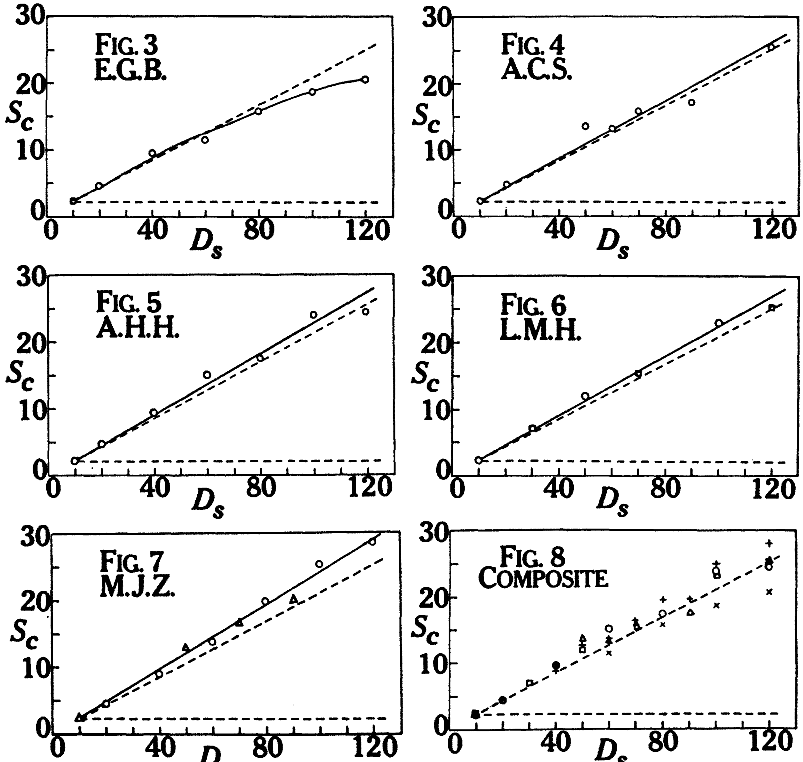
distance; 10 were made by increasing the size of $S_c$ until $O$ reported that the visual impression produced by it was equal in extent to that produced by $S_s$; 10 more were made by decreasing the size of $S_c$. The two procedures gave practically identical results, and for each distance the 20 measurements were averaged to obtain the desired measure of central tendency. A smaller number of results was secured from the other *O*s.

## Binocular Observation

The measurements for the binocular observations are shown in Table I. These data were obtained with binocular regard by altering the diameter of the comparison stimulus $S_c$, until it appeared equal to the standard stimulus (1°) in respect of perceived size, as the distance from $O$ to the standard stimulus was varied from 10 to 120 ft.

The measurements for each $O$ are also exhibited in Figs. 3-7. The coordinates are expressed in linear units. The ordinates give the size of the comparison stimulus (in.), the abscissas the distance (ft.) from *O* to the standard stimulus. Fig. 8 is the composite of the binocular data for all *O*s.

The size of the comparison stimulus $S_c$ in all instances increases with the distance of $S_s$ from *O*. In other words, the apparent size ($= S_c$) of a standard stimulus varies




Figs. 3-8. Binocular Observation: Apparent Size of the Standard Stimulus as a Function of its Distance

Figs. 3-7 show the apparent size of the standard stimulus as its distance from *O* is varied from 10 to 120 ft. Standard stimulus subtended a constant angle of 1° at eye of *O*. Circles are for first sitting; triangles and rectangles are for later sittings. For values of *N*, see Table I. The oblique broken line is the locus of all data obeying the law of size constancy. The broken horizontal line is the locus of all data conforming to the law of the visual angle. Fig. 8 is a composite of the data for all *O*s. Different symbols denote different *O*s.

directly with the distance from *O* to the standard. The specific form assumed by the majority of these functions is surprising, since commonplace experience would lead one to expect diminishing returns for $S_c$ at great distances. Except for the data of E.G.B., which exhibit a curvature that is concave toward the axis of the abscissas, the values of $S_c$ are related to the distance of the standard stimulus by a linear function.

Much has been said concerning the likelihood of securing results intermediate between the limits of size constancy and the visual angle. The binocular data for most of our *O*s do not, however, lie within these limits, but *outside* of them. The most probable function is not only linear in form but it also has a slope greater than that demanded by the law of size-constancy.[13]

At first thought, it seems as if we had here to do with a case in which apparent size is 'more than constant,' that is to say, a case where the apparent size of a receding object increases slightly while the retinal image diminishes greatly. It is quite possible, however, that there is in our equations a space error, such that $S_c$ on *O*'s left is seen a little smaller than an $S_s$ of equal physical size on *O*'s right, so that for subjective equation $S_c$ has to be made a little too large. The discrepancy is of the order 1.12:1, *i.e.* a value for binocular observation is about 1.12 times the corresponding theoretical value for size constancy. In two other similar experiments we have encountered this discrepancy in this direction once and failed to find it once.[14] The chief argument for suggesting that a space error may be operative is that there is available no other sensible interpretation of why constancy should be 'exceeded.' It is our belief that this error—if indeed it be an error, for we have no other evidence than the foregoing—is not psychophysical but instrumental, like some mistake in the distance from *O*'s head to the screen for the comparison stimulus. If such be the source, then the error would also apply to the other three functions discussed below, and a correction would be achieved by a slight clockwise rotation of the functions.

## Monocular Observation

During the monocular observations, *O* wore a leather stop which completely covered one eye. The apparatus, method, procedure and *O*s were the same as employed in the binocular observations. The results for the monocular equations with respect to size are entered in Table II.

Figs. 9-13 show the function that $S_c$ is of $D_s$ for each *O* under the conditions of monocular observation. The open circles represent the first measurements taken at the first sitting; the rectangles and triangles, measurements taken about one week later. The agreement between the first and second sets of measurements provides an index as regards the repro-

[13] Analogous results for 'over-constancy' in color equations have been reported by W. Burzlaff, Methodologische Beiträge zum Problem der Farbenkonstanz, *Zsch. f. Psychol.*, 119, 1931, 177-235.

[14] The discrepancy is measured by the ratio 1.12:1, which applies actually at $D_s = D_c = 10$ ft. as well as elsewhere. We would seem truly to be dealing with a space error and not with a phenomenon of size constancy since the deviation occurs when the standard and comparison stimuli are equidistant. In certain other unpublished experiments with this apparatus we got no space error of this sort. In still other experiments, A. H. Holway and E. G. Boring. The dependence of apparent visual size upon illumination, this Journal, 53, 1940, 587-589, we found a space error in this direction ranging from 1.02 to 1.15, when $D_s = D_c = 100$ ft., and also 200 ft.

ducibility of the functions. The data for each *O* can be fitted with a straight line. No solid lines have been drawn for the data of A.H.H. and L.M.H. (Figs. 11 and 12) since the trend so nearly parallels the law of size constancy. While the results for E.G.B. and A.C.S. tend to lie below the hypothetical line for constant size, those for M.J.Z. lie slightly above it. The scatter of the measurements about the fitted line varies inversely with

TABLE II

MONOCULAR OBSERVATION: APPARENT SIZE OF STANDARD STIMULUS AS A FUNCTION OF ITS DISTANCE

(See Table I for explanation of symbols.)

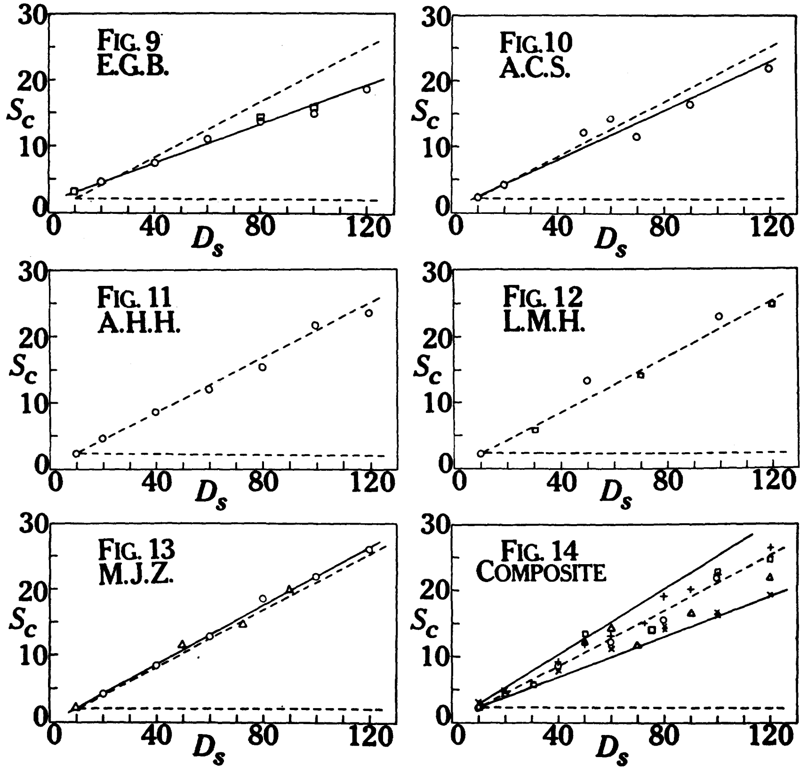
| | E.G.B. (N=20) | | A.C.S. (N=5) | | A.H.H. (N=10) | | L.M.H. (N=5) | | M.J.Z. (N=20) | |
|---|---|---|---|---|---|---|---|---|---|---|
| $D_s$ | $S_c$ | m.v. | $S_c$ | m.v. | $S_c$ | m.v. | $S_c$ | m.v. | $S_c$ | m.v. |
| 10 | 3.0 | 0.27 | 2.1 | 0.17 | 2.0 | 0.15 | 2.1 | 0.18 | 2.1 | 0.20 |
| 20 | 4.7 | 0.40 | 4.3 | 0.36 | | | | | 4.1 | 0.34 |
| 30 | | | | | | | 5.8 | 0.38 | | |
| 40 | 7.5 | 0.38 | | | 8.5 | 0.51 | | | 8.5 | 0.29 |
| 50 | | | 12.2 | 0.34 | | | 13.3 | 0.44 | 11.5 | 0.38 |
| 60 | 11.1 | 0.39 | 14.1 | 0.51 | 12.0 | 0.81 | | | 12.7 | 0.28 |
| 70 | | | 11.5 | 0.40 | | | 14.0 | 0.49 | 14.5 | 0.52 |
| 80 | 12.8<br>13.5 | 1.11<br>0.70 | | | 15.3 | 0.45 | | | 18.7 | 0.62 |
| 90 | | | 16.4 | 0.24 | | | | | 18.9 | 1.08 |
| 100 | 15.0<br>15.8 | 0.91<br>1.13 | | | 21.7 | 1.40 | 22.7 | 0.43 | 22.0 | 0.43 |
| 120 | 18.9 | 1.06 | 22.0 | 0.20 | 23.5 | 0.75 | 24.7 | 0.79 | 26.1 | 0.55 |

the number of measurements. Thus, the data manifest the least departures for E.G.B. and M.J.Z. ($N = 20$), and the greatest departures for A.C.S. and L.M.H. ($N = 5$). The data for all *O*s are plotted in Fig. 14.

The size of the comparison stimulus is a linear function of the accommodated distance from *O* to the standard stimulus. The rate of change in the size of the comparison stimulus, with respect to the distance of the standard stimulus, is accordingly constant, and the slope of the straight line fitted to the average of all the data is 0.0170, which differs insignificantly from the tangent of $1^\circ$ ($= 0.0175$). We cannot, however, conclude that the data for monocular observation closely follow the law of size constancy because of the probable existence of the constant error which we noted in the preceding section. The data for binocular observation are presumably closest to size constancy among the sets of data for the four conditions of this experiment; hence these data for monocular vision, when compared with those for binocular vision, represent a regression away from the law of size constancy toward the law of the visual angle.

## Monocular Observation with an Artificial Pupil

In these experiments, the *O* wore a leather stop over one eye and successively observed the standard and comparison stimuli through an artificial




Figs. 9-14. Monocular Observation: Apparent Size of the Standard Stimulus as a Function of its Distance

Figs. 9-13 show the apparent size of the standard stimulus as its distance from *O* is varied from 10 to 120 ft. Standard stimulus subtended a constant angle of 1° at eye of *O*. Circles are for first sitting; triangles and rectangles are for later sittings. For values of *N*, see Table II. The oblique broken line is the locus of all data obeying the law of size constancy. The broken line parallel to the axis of abscissas is the locus of all data conforming to the law of the visual angle. Fig. 14 is a composite of the data for all *O*s. Different symbols denote different *O*s.

pupil worn in front of the other eye. The pupil was 1.8 mm. in diameter, an aperture in a thin metal disk, which was held in a fixed position at a distance of about 4 mm. from the anterior corneal surface of *O*'s eye by one of the curled rims on a pair of adjustable trial-frames. The results obtained under these conditions are presented in Table III, and graphically in Figs. 15-19.

Fig. 20 contains the results for all *O*s. A comparison of the data in Fig. 20 with the data in any one of the Figs. 15-19 shows that the inter-individual variability exceeds the variability in the data for any individual *O*. These data, lying well below the theoretical line for size constancy,

TABLE III

MONOCULAR OBSERVATION WITH ARTIFICIAL PUPIL: APPARENT SIZE OF STANDARD STIMULUS AS A FUNCTION OF ITS DISTANCE

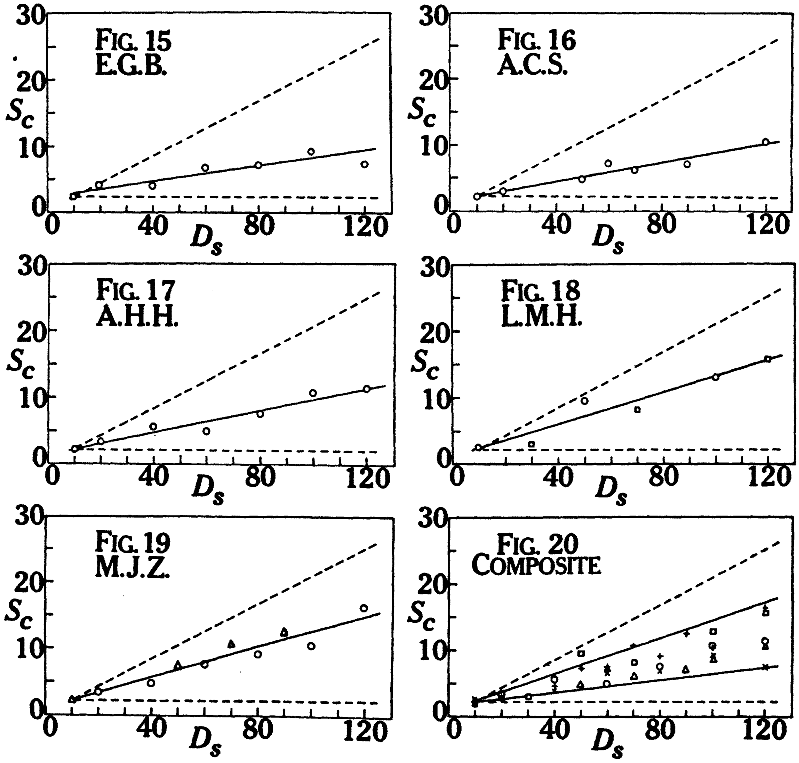
(See Table I for explanation of symbols.)

| | E.G.B. (N=20) | | A.C.S. (N=5) | | A.H.H. (N=10) | | L.M.H. (N=5) | | M.J.Z. (N=20) | |
|---|---|---|---|---|---|---|---|---|---|---|
| $D_s$ | $S_c$ | m.v. | $S_c$ | m.v. | $S_c$ | m.v. | $S_c$ | m.v. | $S_c$ | m.v. |
| 10 | 2.4 | 0.18 | 2.2 | 0.20 | 2.1 | 0.18 | 2.5 | 0.11 | 2.2 | 0.14 |
| 20 | 4.1 | 0.44 | 3.0 | 0.19 | 3.3 | 0.27 | | | 3.3 | 0.27 |
| 30 | | | | | | | 3.0 | 0.19 | | |
| 40 | 4.0 | 0.45 | | | 5.6 | 0.28 | | | 4.8 | 0.20 |
| 50 | | | 4.8 | 0.40 | | | 9.5 | 0.36 | 7.3 | 0.32 |
| 60 | 6.8 | 0.39 | 7.2 | 0.37 | 5.0 | 0.29 | | | 7.7 | 0.36 |
| 70 | | | 6.2 | 0.29 | | | 8.2 | 0.34 | 10.8 | 0.59 |
| 80 | 7.1 | 0.67 | 7.2 | 0.35 | 7.7 | 0.39 | | | 9.2 | 0.35 |
| 90 | | | | | | | | | 12.6 | 0.60 |
| 100 | 9.3 | 0.53 | | | 10.8 | 0.57 | 12.9 | 0.52 | 10.6 | 0.67 |
| 120 | 7.4 | 0.39 | 10.6 | 0.65 | 11.6 | 0.60 | 15.7 | 0.80 | 16.4 | 0.92 |

represent a further regression toward the law of the visual angle, a regression that results from the introduction of the artificial pupil as an observational constraint.

## MONOCULAR OBSERVATION WITH ARTIFICIAL PUPIL AND REDUCTION TUNNEL

The experiments described in the foregoing sections were carried out in reduced illumination. At *O*'s eye the intensity of the light reflected from the surroundings on to a magnesium oxide plate was less than $10^{-3}$ millilamberts. The reflectance of the walls, ceilings, and floors of the corridors, however, was not uniform as viewed from *O*'s position. The consequence was that there were formed various light patterns which provided a sensory ground for the perception of the stimulus. It is plain that the addition of extraneous sensory stimulation of this sort—especially when it might even constitute a vague perception of the space intervening between *O* and the stimulus—ought to be eliminated if we are concerned with an analysis of the parts played by various cues. In other words, we ought to attempt still further to 'reduce' the perception to its fundamental feature, which is the retinal image, just as color constancy and brightness constancy may be 'reduced' to bare retinal excitation by the use of a 'reduction screen.' A reduction screen is a screen with a hole in it. We determined to build a reduction tunnel, a long black tube which would eliminate the perception




FIGS. 15-20. MONOCULAR OBSERVATION WITH ARTIFICIAL PUPIL: APPARENT SIZE OF THE STANDARD STIMULUS AS A FUNCTION OF ITS DISTANCE

Figs. 15-19 show the apparent size of the standard stimulus as its distance from *O* is varied from 10 to 120 ft. Standard stimulus subtended a constant angle of 1° at eye of *O*. Circles are for first sitting; triangles and rectangles are for later sittings. For values of N, see Table III. The oblique broken line is the locus of all data obeying the law of size constancy. The broken line parallel to the axis of abscissas is the locus of all data conforming to the law of the visual angle. Fig. 20 is a composite of the data for all *O*s. Different symbols denote different *O*s.

of reflected light from the surfaces of the corridor, and presumably therefore 'reduce' observation more nearly to the retinal image alone.

Accordingly a long tunnel was constructed to reduce the number and intensity of these extraneous images. The side walls of the tunnel were made of heavy black cloth. The whole affair was supported by steel rods welded together in the form of a square and held up by wooden posts. The greatest length of the tunnel was 100 ft. For shorter distances, the cloth was folded back on itself. Each side of the tunnel measured 3 ft.

In order to determine the nature of the new visual field, we had *O* look down the tunnel monocularly through the artificial pupil, fixate the center

TABLE IV

MONOCULAR OBSERVATION WITH ARTIFICIAL PUPIL AND REDUCTION TUNNEL: APPARENT SIZE OF STANDARD STIMULUS AS A FUNCTION OF ITS DISTANCE

(See Table I for explanation of symbols.)

| | A.C.S. (N=20) | | A.H.H. (N=20) | |
|---|---|---|---|---|
| $D_s$ | $S_c$ | m.v. | $S_c$ | m.v. |
| 10 | 2.2 | 0.19 | 2.2 | 0.21 |
| 50 | 4.4 | 0.37 | 3.4 | 0.32 |
| 100 | 6.0 | 0.55 | 6.8 | 0.67 |

of the standard stimulus, and report the appearance of the field. The standard stimulus was seen standing out in clear relief against the darkened background. Most of the various reflections were diffuse and greatly reduced in intensity. Nonetheless, there still remained a perceptible (and annoying) haze which surrounded the primary stimulus. This border-like haze took on the form of a square and was localized midway between the *O* and the standard stimulus.

The results obtained by equating the perceived size of the stimuli under these conditions are presented in Table IV and Fig. 21 for two *O*s, each of whom worked entirely without knowledge of the other's results. Measurements were made at three distances, 10, 50 and 100 ft. The slope of this line, which indicates the trend of these observations, is less than for any of the other conditions. These results are, obviously from Fig. 21, closer to the law of the visual angle than they are to the law of size constancy. They show that the tunnel actually did 'reduce' the perception, although not entirely to the visual angle.

## DISCUSSION

The net result of these experiments is exhibited in Fig. 22, which shows the functions for the various conditions brought into relation with each other as straight lines with different slopes. These functions summarize about 1,500 measurements altogether. Their slopes diminish regularly if the functions are considered in the order in which they have just been discussed. How are we to interpret such a relationship?

In 1911 Katz introduced into the psychology of perception the concept of *reduction*.[15] The perceived phenomenon is a resultant of many determinants. Some one of them may be *primary* in the sense that it is essential to the perception although it may not play the principal role in determining

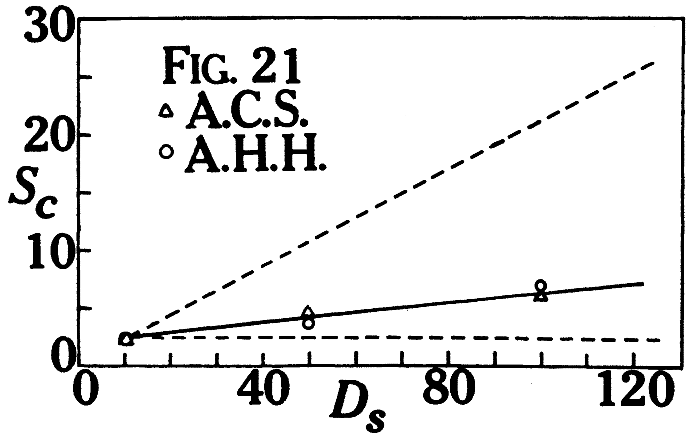



FIG. 21. MONOCULAR OBSERVATION WITH ARTIFICIAL PUPIL AND REDUCTION TUNNEL: APPARENT SIZE OF THE STANDARD STIMULUS AS A FUNCTION OF ITS DISTANCE

The figure shows the apparent size of the standard stimulus as its distance from *O* is varied from 10 to 100 ft. The standard stimulus subtended a constant angle of 1° at eye of *O*. The oblique broken line is the locus of all data obeying the law of size constancy. The broken line parallel to the axis of abscissas is the locus of all data conforming to the law of the visual angle. The circles represent the data for A.H.H.; the triangles for A.C.S. Each plotted datum is based on 20 measurements.

the exact form or quality or amount of the perception. For instance, in the case of visual brightness, which Katz was considering, illumination of the perceived object is a primary factor, yet the phenomenal brightness is actually determined by many other factors that enter otherwise into the perception. If some of these additional determinants can be eliminated, then the perception can be reduced in the direction of the primary determinant. So Katz invented the "reduction screen," a screen with a hole in it so arranged that, when a colored surface is seen through the hole and all the circumstances of its relation to the surrounding field are excluded by the remainder of the screen, then the brightness, instead of remaining "constant" at the value proper for the perceived object, is "reduced" to a datum dependent almost entirely upon the actual retinal illumination.

[15] D. Katz, Die Erscheinungsweisen der Farben, *Zsch. f. Psychol.*, Ergbd. 7, 1911, esp. 36-39.

In a similar manner we may regard the present series of conditions as representing successive reductions of the size perception. Let us list these conditions in order, adding as additional items the two theoretical limits of variation. Here the primary determinant is, of course, visual angle or retinal size. It is toward it that reduction is undertaken.

*(1) Size constancy.* It is possible that size constancy represents one limit of variation, that perceptual organization, as Brunswik has suggested,[16]

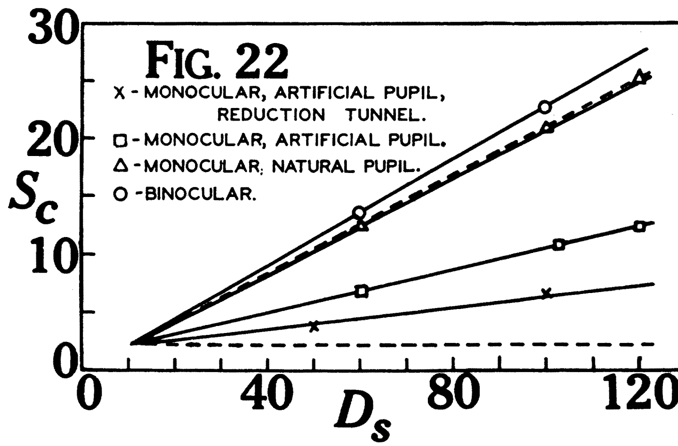



FIG. 22. DETERMINANTS OF APPARENT VISUAL SIZE WITH DISTANCE VARIANT

Apparent size as a function of distance for four sets of conditions. The figure is based on the averages of all the data obtained in the present experiment. The slope of the function relating apparent size to distance diminishes continuously as the mode of regarding the stimuli is altered from direct binocular observation, to direct monocular observation, to monocular observation through a small artificial pupil, to monocular observation through the artificial pupil and a long black reduction tunnel. As the number of extraneous cues is diminished, the slope of the function approaches zero as a limit, *i.e.* it approaches the law of the visual angle.

occurs in the interest of stabilizing the perceptual world. The organism utilizes, therefore, additional 'cues' which tend to keep the apparent size of an object constant when its visual angle varies with changing distance. According to this view, we should not expect to find an over-compensation, by which a receding object would increase in apparent size while its retinal image diminished.

[16] E. Brunswik, Die Zugänglichkeit von Gegenständen für die Wahrnehmung und deren quantitative Bestimmung, *Arch. f. d. ges. Psychol.,* 88, 1933, 377-418. See esp. the section on intendierte und intentional erreichte Wahrnehmungsgegenstände, pp. 378-387, and the section on Bestimmung des intentional erreichten Gegenstandes, pp. 387-411, which deals with der Grad der Dingkonstanz. The Helmholtzian conception of unbewusster Schluss seems by this route to be reentering the psychology of perception.

*(2) Binocular observation.* Free binocular observation presumably employs all the determinants available, and would thus be, as we find, the least reduced perception. It might therefore achieve size constancy or fall short. Our data, however, show over-compensation; the slope of the function for binocular observation exceeds the slope of the dotted line for size constancy in Fig. 22. This position of the line for binocular observation, as we have already noted, may merely indicate the existence of a space error in the experiment. If that assumption be correct, then the 'true' function for these data of binocular observation lies with the line for size constancy or below it.

*(3) Monocular observation.* The stopping of vision from one eye is the first step in reduction of the perception. By it all binocular retinal conditions for the perception of distance are eliminated. It is obvious that the reduction of the perception from size constancy toward the law of the visual angle must depend upon the elimination of cues to distance, for the organism can compensate for diminution of retinal size with increase of distance only if cues to distance are available—only if it 'knows' how far away the object is and thus how much to compensate for distance. Reduction, therefore, must consist mainly in the removal of cues to distance.[17]

*(4) Artificial pupil.* The use of an artificial pupil with monocular observation still further reduces the slope of the function (Fig. 22) and may thus be supposed to eliminate some more cues to the distance of the standard stimulus. Perhaps the stopping down of the pupil makes accommodation less effective and thus reduces its effectiveness as a differentia of distance.[18]

*(5) Reduction tunnel.* Some faint illumination from the stimuli was visible by reflection from the surfaces of the corridor. The long black tunnel, 3 x 3 ft., was designed to eliminate these cues to distance and thus to reduce the perception entirely to retinal size. The result was not entirely successful. There was still a light haze visible within the tunnel which conceivably may have provided an indication of distance. At any rate the slope of the function was not reduced to zero. Nevertheless, with the tunnel the perceptual field became much more homogeneous, and the slope of the function was greatly diminished.

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[17] Monocular observation also reduces apparent size because it reduces the total retinal illumination; cf. Holway and Boring, *op. cit.*, this JOURNAL, 53, 1940, 587-589. Since it affects both the standard and comparison stimuli, leaving their relation unchanged, it need not be considered here.

[18] The artificial pupil also reduces apparent size by reducing retinal illumination, but, like the reduction in monocular vision, it affects both the standard and comparison stimulus and can be ignored here.

*(6) Visual angle.* Retinal size, as indicated by the visual angle, must be the limit of reduction and yield a function in which the slope is zero. For all that has been said by Gestalt psychologists against the validity of the law of the visual angle, it would nevertheless appear that, when no relevant datum other than retinal size is available, then the perception of size will after all vary solely with the visual angle. That statement is a tautology and must be true. Size constancy can be the law of size, therefore, only when determination is complex.

The following ratios show the relative slopes of the functions under discussion. To them are added the values for the theoretical laws of size constancy (1.00) and of visual angle (0). The "actual data" are the slopes as they occur in Fig. 22. The "adjusted data" are the slopes as they would be if we correct for a possible space error by rotating the functions clockwise through an angle of 10′, so as to bring the line for binocular observation to where we think it should be, *i.e.* below the line for size constancy. These adjusted data are also plotted in Fig. 23.

| | Size constancy | Binoc. obs. | Monoc. obs. | Artif. pupil | Red. tunnel | Vis. angle |
|---|---|---|---|---|---|---|
| Actual data | 1.00 | 1.09 | .98 | .44 | .22 | 0 |
| Adjusted data | 1.00 | .93 | .81 | .30 | .08 | 0 |

Our general conclusion from all these data is hardly more than a restatement of the obvious. The organism can perceive the size of an object as constant, even though its distance changes, provided the perception is complex enough to provide the essential differentiae. When the preception is reduced by the elimination of some of these determinants, the law of the variation of apparent size with distance approaches the law of variation of the remaining determinants. If the perception could be reduced to a single determinant—retinal size or any other—then apparent size would have to vary in accordance with the mode of variation of this sole remaining determinant. There is no alternative hypothesis.

## Summary

The apparent size of a standard stimulus subtending a visual angle of one degree was measured as the distance of the standard was varied from 10 to 120 ft. Functions relating apparent size to distance were obtained from 5 *O*s under four different sets of conditions: (1) direct binocular regard; (2) monocular regard; (3) monocular regard through a small artificial pupil; and (4) monocular regard through the artificial pupil and a long black reduction tunnel. For each of these conditions the most probable form of the function relating apparent size to distance was found to be linear.

These conditions, considered in the order in which they have been named, represent a serial reduction of the size perception. In binocular regard apparent size is the resultant of the interoperation of many determinants, which are successively reduced in number in the three remaining sets of conditions. This reduction is paralleled by a consistent change in the slope of the line that relates apparent size to distance. The limits of variation of this slope are—at least approximately—(1)

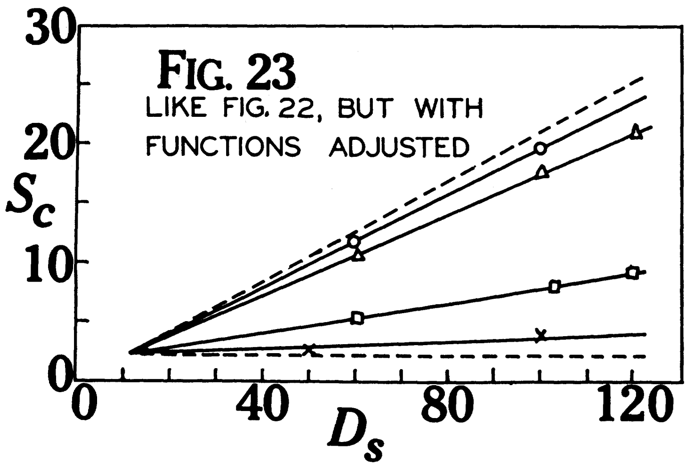


FIG. 23. DETERMINANTS OF APPARENT VISUAL SIZE WITH DISTANCE VARIANT
This figure is the same as Fig. 22, except that the four functions have been rotated clockwise through an angle of 10 min., in order to bring the function for binocular observation below the function for size constancy, as we think it would have to be, and as correction for a space error might require.

the function for size as constant in spite of change of the perceived object's distance and (2) the function for size as proportional to the visual angle subtended by the perceived object. Binocular regard gave a function close to the function for size constancy. Reduction of the perception from binocular regard brought the function nearly, but not entirely, to the slope for apparent size as wholly dependent upon retinal size.