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PERCEIVED DEPTH BETWEEN FAMILIAR OBJECTS

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Perceived Depth Between Familiar Objects*

I. Introduction.

If two luminous rectangles of the same shape but with different retinal sizes are viewed monocularly in an otherwise dark room, the retinally smaller rectangle will be perceived to be the more distant rectangle. This is an example of the relative size cue to the perceived depth between objects, with the perceived depth between objects being termed a perception of exocentric distance.[4] The rectangles in this case are nonfamiliar objects in the sense that there is no reason why they should be perceived as having one size rather than another. If the rectangles are patterned, however, so as to appear as familiar objects, for example, as playing cards, they will have a perceived size which, it would be expected, would be the same as the physical size of a playing card, and again the card with the smaller retinal size would appear to be the more distant. This is an example of the *familiar* size cue to perceived exocentric depth. The similarity of these two cases raises the question as to whether the exocentric distance cue of familiar size can be subsumed under that of relative size.[6,7,8] This is answered in the affirmative in a study by Hochberg and Hochberg[6] in which it was found that the perceived depth between different kinds of similarly shaped familiar objects was determined by the retinal, not the assumed, sizes of the objects. Epstein and Baratz[2] (Experiment II), however, came to a different conclusion. In this latter experiment the perceived depth was measured between objects representing a dime, a quarter, and a half dollar, presented in pairs. Each coin subtended three possible retinal sizes so that the relative and familiar size cues could be placed in agreement or in opposition. The results of this study indicate that the perceived depth between the pairs of coins when the two cue systems were in opposition was in agreement with familiar, not relative, size. Recently, it has been asserted after reviewing the evidence[3], that the familiar size cue cannot be subsumed under the relative size cue but that both can be subsumed under the concept of perceived size S′ per unit of retinal size (visual angle) θ of the object. Specifically, it has been asserted that in the absence of other distance cues, two objects which have the same values of S'/θ, will appear equidistant. If the two objects have different values of S'/θ, the object with the largest value of S'/θ will appear to be the more distant object.

An advantage in defining the size cue to exocentric distance in terms of the S'/θ values of the several objects is that the ratio S'/θ can be applied to objects of irregular as well as of regular shape.[3] For example, suppose that an irregularly shaped object such as a door key is presented in a plane frontoparallel to the observer *(O)*. According to the above discussion, since all parts of the key appear to O to be equidistant, all parts of the key should have the same value of S'/θ. If the perceived size of any portion of the key and the θ value of this same portion of the key are known, the value of S'/θ for all the key is determined. It follows from this definition of the size cue to exocentric distance, that this cue will occur between any familiar objects regardless of their irregularity and differences in shape and indeed between any objects for which S'/θ values can be specified. The purpose of the present experiment is to test the hypothesis that the perceived depth between two familiar objects of different retinal and perceived sizes will differ when the S'/θ values of the objects differ, with the object having the larger S'/θ appearing to be the more distant object of the pair.

II. Method.

Apparatus. Five photographic positive color transparencies of familiar objects (centered in 3¼ X 4 inch slides) were used as stimuli. The familiar objects were a box of Luden's cough

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drops, a half dollar, a small Scotch Tape dispenser, a door key, and a small tube of Crest toothpaste. All of the objects were photographed with their largest side frontally oriented with respect to the camera. The objects were photographed against a black background so that only the image of the object was transparent. The transparencies were mounted in front of light boxes consisting of diffusing surfaces homogeneously transilluminated by flourescent lamps. The luminances of the sources were adjusted to match the relative luminances of the real objects from which the transparencies were made. The relative luminances of the real objects were measured while using a diffuse white illumination at a constant distance from all the objects. When mounted on the light sources, the values of the most luminous parts of the transparencies were 1.2, 1.0, 0.6, and 0.6 ft.–L for the half dollar, tube of toothpaste, box of cough drops, and key, respectively. The most luminous area of the tape was too small to be measured with the available photometer. The stimuli were always presented in pairs in a frontoparallel plane 1.33 meters from *O*'s eye with the centers of the two images of each pair always separated by 23.3 cm. (10°) and centered with respect to the median plane of the right eye. A +.75 diopter lens mounted in the right eyepiece optically placed the photographs at an infinite accommodative distance from *O*. The observation was always monocular (right eye only). Considerable care was taken to eliminate all extraneous illumination so that the stimuli appeared to *O* to be real objects presented in an otherwise totally dark visual field. A head and chin rest were located at the observation position, with the observation position enclosed in black cloth so as to eliminate any extraneous light. Communication between the experimenter *(E)* and *O* occurred by means of speakers and microphones. A continuous masking noise was presented to *O* except when *E* was communicating with him. A shutter positioned in front of the viewing aperture permitted *E* to change the stimuli without being observed by *O*. A contact relay on the head rest insured that *O*'s head was properly positioned for the observation. A light adaptation surface[10], located to *O*'s left, was designed to provide a homogeneous visual field with a brightness of 15 ft.–L, which was activated only when *O*'s head was appropriately placed in the adaptation apparatus.

A hand adjustment apparatus was used by *O* to indicate the perceived size (S′) of the stimulus objects. The apparatus consisted of two vertical square rods (½ in. thick) located at the level of *O*'s waist. The left rod was fixed, and the right rod could be moved laterally. A meter stick was attached to the right rod to measure the amount of separation of the inner edges of the rods. Verbal reports were used to measure the perceived distance to the objects and the perceived depth between them.

Procedure. Twenty men served as *O*s. All *O*s were between the ages of 18 and 35 years and had at least 20/20 acuity with their right eye as measured at both the near and far points using the Bausch and Lomb Orthorater. The five stimuli were presented in pairs, with each stimulus equally often on the right and left. The resulting 20 pairs were presented in a balanced Latin Square design[1] with a different sequence of pairs used with each *O*.

The instructions to *O* emphasized that apparent judgments were to be made with respect to both size and distance. A previous study had indicated that when instructed to make judgments of the apparent size of a familiar object in an otherwise dark visual field, some *O*s made angular size judgments, possibly with respect to an arbitrary distance.[5] Since apparent size judgments were required in the present experiment, this problem was avoided by showing *O* a simple diagram which illustrated the difference between judgments of apparent and angular size. After the instructions, *O* sat for ten minutes in the totally dark observation booth, looked into the light adaptation surface for 30 seconds, and then positioned his head in the observation position. Following this, the shutter was raised revealing the pair of familiar objects.

According to a balanced order, for each pair of objects, *O* reported in feet or inches, or in some combination of both, the apparent distance of one of the two objects from himself. *O* indicated which, if either object appeared to be more distant and reported the perceived depth between the objects (again in feet or inches or a combination of both). Following this, *O*, using the hand adjustment apparatus, adjusted the distance between the rods until this lateral distance seemed to be the same as the apparent right-left extent of the object. This adjustment was completed twice for each of the objects of the pair. This total process, except for the ten minutes in the dark, was repeated for each pair of familiar objects.

III. Results.

The angular sizes (θ) of the five familiar objects are given in Table 1 together with the simulated sizes (S) and distances (D) of the objects.

TABLE 1. Average Perceived Size S' and Perceived Distance D' resulting from Objects of Visual Angle θ and Simulated Width and Distance S and D.

	θ (rad)	D (cm)	S (cm)	D' (cm)	S' (cm)
Crest	.0428	299	12.8	159	10.3
Drops	.0428	234	10.0	126	9.1
Tape	.0578	128	7.4	86	7.8
50¢	.0345	87	3.0	81	5.3
Key	.0855	63	5.4	66	7.6

The simulated sizes are the widths (left-to-right extents) of the real objects when oriented as in the transparencies, and the simulated distances are the distances from O at which the objects would have to be placed to subtend the particular angular size (θ in rad. $= S/D$). The value of D' is the average reported distance, converted to centimeters, at which O perceived the object to be from himself. The value of S' is the average reported size (width) of the object, as determined by using the hand adjustment apparatus. From Table 1, S and S' are similar except in the case of the half dollar and key. However, D and D' are only similar for the smaller values of D. As D increases, D-D' increases until at a D of approximately 3 meters, D' is only about half the value of D.

The relation between average values of S'/θ and average values of the reported depth (d') between the objects of a pair is given in Table 2 under "Obtained Values." The average values of S'/θ for each object are shown in the outer column and upper row. The average values of d' are given to the right or below the object names, with each value of d' being the average reported depth between the pair of objects comprising that column and row. Each value of d' is the average of 20 scores, one from each O, with each score being the average perceived depth between the two objects with their right-left positions systematically reversed. Table 2 is arranged to allow examination of the validity of the hypothesis that the perceived depth between the objects is determined by the magnitude of the difference of the S'/θ values of the objects. The objects are arranged in the left half of Table 2 so that the value of S'/θ increases from left to right and from top to bottom. If the above hypothesis is correct, all the values of d' within the left half of Table 2 should be positive and should decrease from left to right and from bottom to top. Nine of the ten values of d' are positive, and the tendency for these values to change in the expected directions is clear. The data in the left portion of Table 2 can be summarized as follows: (1) In general, the familiar object appearing to be more distant had the greater value of S'/θ; (2) the greater the

TABLE 2. Average Values of Perceived Distance d' (in Centimeters) between Objects Whose Average Values of Perceived Size S' (in Centimeters) Per Unit of Visual Angle θ (in Radians) are Shown in the Column and Row Headings. The Physical Size S (in Centimeters) and Visual Angle θ (in Radians) of the Familiar Object and the Physical Depth d (in Centimeters) between the Objects Simulated in the Experiment are Shown in the Right Portion of the Table.

Obtained Values

	S'/θ	88	134	152	211
S'/θ	Object	Key	Tape	50¢	Drops
		d'			
134	Tape	26			
			d'		
152	50¢	22	−6		
				d'	
221	Drops	65	37	46	
					d'
239	Crest	89	77	68	35

Simulated Values

	S/θ	63	87	128	234
S/θ	Object	Key	50¢	Tape	Drops
		d			
87	50¢	24			
			d		
128	Tape	65	41		
				d	
234	Drops	171	147	106	
					d
299	Crest	236	212	171	65

difference between values of S'/θ, the greater, in general, was the perceived depth between the familiar objects.

The right portion of Table 2 specifies the physical (simulated) size per unit of retinal size S'/θ, and the physical (simulated) depth d between real objects which would be required when using actual objects (not photographs) in order to produce the visual angles of the stimuli. It is clear from Table 2 that, although the S'/θ and S/θ values were reasonably similar, the d' values were often considerably smaller than the d values, particularly at the larger values of d.

The left portion of Table 2 indicates the importance of relative values of S'/θ in determining the perceived depth between two familiar objects. It will be noted, however, that the form of the relation between relative values of S'/θ and d' has not been specified. One possible expression of this relation can be obtained from the size-distance invariance hypothesis[9] which states that

$$S' = K\theta D' \qquad (1)$$

where D′ is the perceived distance to the familiar object of retinal size (visual angle) θ and perceived size S′ and K is an observer constant. It follows from Equation 1 that

$$d'_{ef} = \frac{1}{K}\left(\frac{S'_f}{\theta_f} - \frac{S'_e}{\theta_e}\right) \qquad (2)$$

where e and f refer to the two objects whose separation in depth is being judged and $d'_{ef} = D'_f - D'_e$.[3] In order to test Equation 2, the average perceived depth (d') between the two objects of a pair was determined and related to the average (algebraic) difference between the S'/θ values for the two objects of the same pair with the smaller value of S'/θ always subtracted from the larger. The Pearson product-movement correlation coefficient between $S'_f/\theta_f - S'_e/\theta_e$ and d'_{ef} is .81, which is significant beyond the .01 level (t=3.91). Values of r were also computed for the data from each O. The average value of r (.54) was significant at the .01 level (t=7.24). But, it should be pointed out that large individual differences sometimes occurred in the r values (σ_r=.33) with a range of r from −.42 to .94.

IV. Discussion.

The results from this experiment clearly support the view that in the absence of other depth cues, the occurrence of different values of S'/θ between two objects is a sufficient condition for the perception of depth between the objects with the object having the larger value of S'/θ being perceived as the more distant object. It follows from this experiment that it is neither the difference in perceived size nor in retinal size which defines the significant variable in the size cue to depth, but rather the change in perceived size per unit of retinal size (visual angle) between the objects. The size cue to relative distance occurs, therefore, between irregularly as well as regularly shaped familiar objects. It is probable that it occurs between any objects which have perceived sizes regardless of their shape or complexity.

It appears from the significant correlation coefficient between d' and differences in S'/θ that Equation 2 is at least consistent with the obtained results. This does not mean, however, that the perceived distances D' and d' are necessarily veridical, i.e., are similar to D and d. The perceptions of depth tend to be correct only for the smallest values of D and d with the perceptual error (defined by D-D' or d-d') increasing with increases in D and d. Clearly K in Equations 1 and 2 is not unity.

It will be recalled that D' and d' were determined by separate judgments. Nevertheless, the perceptual errors in D' and d' are closely related. This can be seen by comparing the average obtained d' with the d' values obtained by subtracting the appropriate values of D' from each other. It appears that Os on the average are consistent in their judgments. For example, if one object of a pair were perceived to be at 5 feet and the other at 3 feet, the perceived depth between them as directly indicated by a separate report would tend to be 2 feet.

The results from this experiment lend support to the notion that the use of a comparison field or comparison objects can invalidate the resulting measurement of the perceived distance to objects or the perceived depth between them.[3] If each object is perceptually localized in the comparison field by S'/θ differences occurring between the experimental objects and the objects in the comparison field, it would be clear that the perceived depth in the comparison field is determining, not measuring, the perceived distance to or between the experimental objects.

Generalizing the results from the present experiment, it follows that familiar size is a ubiquitous cue to exocentric depth. It occurs between any objects or any parts of objects of any size or shape whenever these objects have perceived sizes. Usually this cue system is studied in the laboratory as occurring between different visual angles of geometrically-regular familiar objects of the same shape. Probably, regularly-shaped similar objects are used because of the difficulty in specifying or comparing the visual angle θ of irregularly or differently shaped objects. The concept that S'/θ is the significant factor in the familiar size cue to exocentric distance both avoids this problem and asserts that the size cue to exocentric depth can occur between objects in a wide variety of situations.

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