

**PROBLEMS IN DEPTH PERCEPTION:**  
Perceived Size and Distance of Familiar Objects

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## PROBLEMS IN DEPTH PERCEPTION:

### Perceived Size and Distance of Familiar Objects

#### I. Introduction.

Familiar size is usually regarded as an important empirical cue determining the apparent distances of objects. The learning process that is assumed to occur in the development of this distance cue depends upon the relation between the retinal size of an object and its physical distance from the observer ( $\theta$ ). A simple explanation of the process involved in this cue system is as follows. In a situation in which many cues are present to determine the perceived distance of the familiar object,  $\theta$  might be expected to learn to associate the retinal size of the familiar object with its perceived distance. As the result of many such associations involving the same familiar object at different distances, presumably  $\theta$  would perceive the familiar object as being at a particular distance from himself solely as a consequence of the presence of a particular retinal size. Clearly, such a learning process would be expected to result in a proportionality between the physical distance  $D$  and the perceived distance  $D'$  of the object from  $\theta$ ; i.e.,

$$D' = C D, \quad (1)$$

where  $C$ , the constant of proportionality, is unity if the resulting perception of distance is veridical. Although this simple account of the learning process involved in familiar size as a cue to distance may seem convincing, it raises several questions. It is by no means certain that the observer can "see" the size of his retinal image.<sup>1,2</sup> By this it is meant that it is not certain whether the number of millimeters or the number of retinal receptor units subtended by the retinal image (its absolute size) can be a datum of perception. If the absolute size of the retinal image is not responded to by  $\theta$  at some level of neural organization, it would seem reasonable that the absolute retinal size of the familiar object cannot become associated with a perceived distance.

A second difficulty that enters this description of familiar size as a distance cue is the specification of retinal size. Should retinal size be defined as a linear extent on the retina or as an area on the retina? Neither definition is easy to apply to the retinal size resulting from an irregularly shaped object such as a tree. A learning problem parallels this problem of specifying the stimulus. Which aspect of retinal size (linear extent or area or some other dimension) is associated through past experience with perceived distance? These different aspects of retinal size are complexly related to object shape and can be different functions of the physical distance of the object from  $\theta$ . If it is assumed, for example, that *linear* extents on the retina are associated with apparent distance, which of the many possible linear extents is involved? Perhaps the learning occurs only with respect to the retinal extent of some salient feature of the object. If, on the other hand, the learning includes all linear extents on the retina, it might be hypothesized that irregular objects (objects whose definition requires the specification of many linear extents) would be more difficult to associate with distance than would regular objects.

A second explanation of the familiar-size cue to distance involves the relation between perceived size and perceived distance. The size-distance invariance hypothesis asserts that for a given visual angle  $\theta$  (retinal size), the ratio of perceived size to perceived distance is a constant.<sup>3</sup> This can be expressed<sup>4</sup> as

$$S'/\theta = K D' \quad (2)$$

The term  $S'$  is the perceived (or apparent) size of the object,  $\theta$  is the visual angle or retinal size of the object expressed in radians,  $D'$  and  $D$  have the definitions given previously, and  $K$  is an observer constant. If familiar objects have perceived sizes because they are familiar, it follows

that the familiar-size cue to distance is an instance of the size-distance invariance hypothesis.<sup>5</sup> The learning process involved in this second explanation must be more complicated than that in the first explanation since perceived size as well as retinal size must be associated with the familiar object and in turn associated with perceived distance.

The second explanation of familiar size as a cue to distance probably is superior to the first in that familiar or assumed size does affect perceived size,<sup>6</sup> and it is clear that perceived size and perceived distance are related in some manner.<sup>7</sup> The problems involved in the first type of explanation are, however, also present in the second. Both explanations require that the absolute size of the retinal image of the familiar object is a stimulus event that is available for the learning process, both require a definition of retinal size that is relevant to objects of irregular as well as regular shape, and both are vague as to which aspect of retinal extent is related by past experience to perceived distance. A possible solution to the problem of specifying the significant variable involved in the size cue is found by considering  $S'/\theta$  in Equation (2) as a single term. It has been asserted that relative values of  $S'/\theta$  constitute the size cue to the perceived depth between objects (a perception of relative depth) where  $S'$  is the perceived size associated with the frontally oriented object whose retinal size is  $\theta$ .<sup>7</sup> The term  $S'/\theta$  is the perceived size per unit of retinal size. It is suggested that objects (and all parts of objects) that appear at the same frontoparallel plane have equal values of  $S'/\theta$ . For example, for a tree all parts of which appear in the same frontoparallel plane, the perceived width of the trunk per unit of visual angle (retinal size) of the trunk width will be the  $S'/\theta$  value for all other portions of the tree. Also, it is suggested that objects or parts of objects that appear at greater or lesser distances have greater or lesser values of  $S'/\theta$ , respectively. If Equation (2) were correct, it would be possible to apply  $S'/\theta$  to the perception of the distance of a familiar object from  $O$  (a perception of absolute distance) as well as to perceived relative depth. From this point of view, instead of learning to associate a particular distance with each particular retinal size of each particular familiar object, an  $O$  merely would

learn to associate a scale of  $S'/\theta$  with a scale of  $D'$ . Assuming that such learning had occurred, any effective determiner of the size of any portion of a frontoparallel object would result in the object having a specific  $S'/\theta$  and, therefore, according to Equation (2), would also result in a perception  $D'$  that the object is at a specific distance.

It is possible that familiar size is an inadequate cue to the perceived distance of objects from  $O$  while remaining an adequate cue to the perceived distance between objects. It has been stated that relative values of  $S'/\theta$  can provide cues to perceived relative distance independently of perceptions of absolute distance.<sup>2,7</sup> This is equivalent to asserting that the perceived relative depth between two objects as a function of the familiar-size cue is not a result of  $O$  perceiving the distance of each of these objects from himself and subtracting the lesser from the greater perceived distance. The purpose of the present study is to investigate both the adequacy of familiar size as a cue to perceived distance, and the relation between perceived absolute and perceived relative depth from this cue system.

The relation between familiar size and perceived absolute distance usually has been investigated by using comparison fields against which the perceived distance of the experimental object is judged. It has been pointed out that this method permits the direct comparison of  $S'/\theta$  values between the experimental object and parts of the comparison field and, therefore, does not necessarily measure the perceived absolute distance that the familiar object would have if the comparison field were not present.<sup>7</sup> If comparison fields are defined as *any* visual field or object that occurs either simultaneously with or in the temporal vicinity of the experimental object, the importance of this objection is increased. From this point of view, comparison fields are not limited to measurement fields deliberately introduced by the experimenter ( $E$ ), but are visual fields of any sort encountered by  $O$  prior to or during the experiment. It follows, for example, that one presentation of a familiar object becomes a comparison field for subsequent presentations of the same or different objects to the same  $O$ . This example suggests that if the relation between familiar size and perceived absolute (rather than perceived relative) distance is to be measured, the familiar object should be the

only visual stimulus present and successive presentations of the familiar object to the same  $O$  should be avoided. Only a few studies have met these requirements. In a study by Gogel, Hartman, and Harker,<sup>8</sup> three retinal sizes of a seven-of-spades playing card were presented, in an otherwise dark visual field, to four groups of 20  $O$ 's with three of the four groups receiving different retinal sizes in the first presentations. The perceived distances of the playing cards were measured by verbal reports and by throwing darts. It was concluded from the average results from the first presentations that different perceptions of absolute distances did not occur as a consequence of the different retinal sizes. Perceived relative distance, however, occurred between successive presentations of the different retinal sizes to the same  $O$ . These results suggest that the perception of relative depth from familiar size cannot always be explained as a difference between two perceptions of absolute distance. Baird<sup>9</sup> presented different angular sizes of a rectangular strip of light to three different groups of 10  $O$ 's in an otherwise dark visual field. The  $O$ 's verbally estimated the distance to the rectangular strip after being informed that the length of the strip was 12 inches. The average response of each group was approximately that which would be expected from the particular retinal size and the assumed size of 12 inches. Considerable intersubject variability occurred, however, and significant median differences were present only between the largest and each of the other two retinal sizes. While it is questionable whether the information that the strip was 12 inches long resulted in the perception of a 12-inch length, it seems from this study that, at least for the largest retinal size used, some variable associated with retinal size had a behavioral if not a perceptual consequence. Epstein<sup>10</sup> presented photographs of one of three coins (a dime, quarter, or half-dollar) separately to each of three groups 15  $O$ 's and used objects in a comparison field to measure the perceived absolute distance and perceived size of the coins, which were always at 135 cm from  $O$  and subtended identical visual angles. The average results were approximately those which would be expected if familiar size were a fairly veridical cue of perceived absolute distance. In order to determine whether these results were an artifact of the use of comparison fields, Epstein<sup>11</sup> repeated the

experiment, with different  $O$ 's, using nonvisual measures of perceived size and distance. To give the  $O$ 's experience in the use of the nonvisual measures, a training session was introduced prior to the experimental session. In the training session, the size and distance of copper disks having approximately the diameter of a dime, quarter, or half-dollar were judged under full-cue conditions using correction procedures. All three disks were located at each of the three distances that the coins would have to be in order to produce approximately the constant angular size used later in the experimental session. The results obtained in the experimental session were similar to those obtained in the earlier experiment. Epstein concluded that the relation between perceived size and perceived distance found in the earlier study is not a methodological artifact of the use of comparison fields. If comparison fields can be defined to include visual fields presented in the training session shortly before presenting the experimental objects, however, it is likely that the methodological problem involved in the use of comparison fields was equally present in both studies.

## II. Apparatus.

In the present study, the role of familiar size in the perception of distance was investigated with measurements made of the perceived size ( $S'$ ) as well as the perceived distance ( $D'$ ) from  $O$ . A ten-of-clubs playing card was the familiar object of the study. The playing card was presented under both static and dynamic conditions. In the static conditions, the retinal size of the card stimulus remained constant for any single presentation. In the dynamic conditions,  $O$  could vary the retinal size of the playing card while viewing it.

*A. Static and Dynamic Situations.* The apparatus for producing the card stimuli for both the static and dynamic presentations is illustrated in Figure 1. The  $O$  monocularly viewed an image of a playing card ( $I$ ) on a screen ( $W$ ) through mirrors  $M_1$  and  $M_2$  with the remainder of the visual field totally dark. The screen was 400 cm from  $O$  as measured along the optical path from the viewing position. The image on the screen was produced by mounting a positive transparency  $T$  of the playing card on an otherwise opaque baffle placed in front of a point source of light ( $P$ ). The light was produced by means

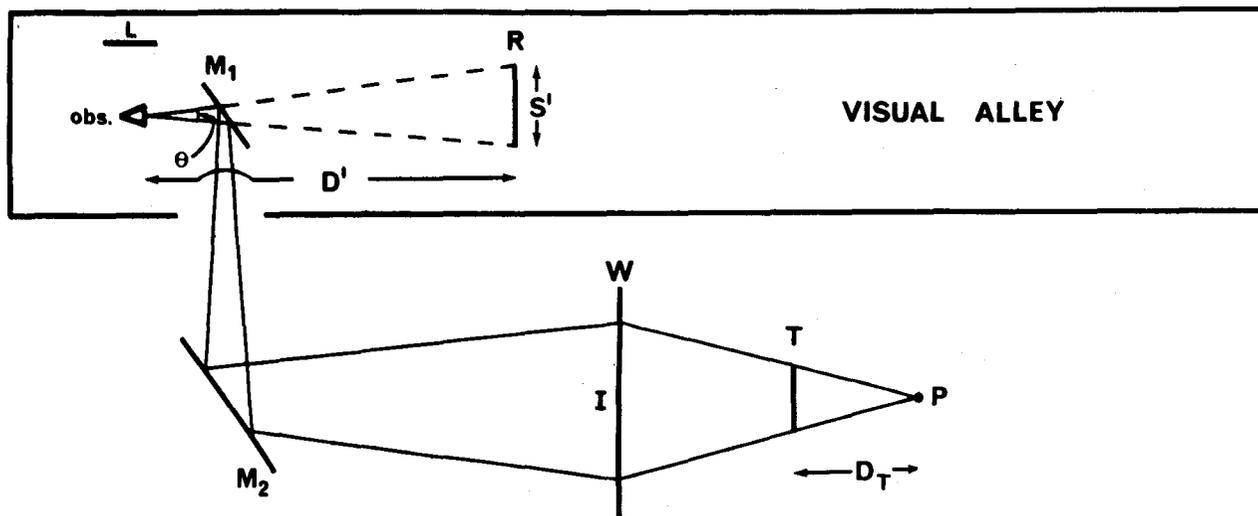


FIGURE 1. A top-view schematic drawing of the apparatus and visual alley.

of a 300-watt Sylvania concentrated-arc lamp with a source diameter of 0.11 inch. In order to reduce image distortion resulting from the finite size of the source, a negative lens ( $L$ ) with a focal length of 11 mm was placed a short distance in front of  $P$ . Light from the point source  $P$  passed through the transparency  $T$  to produce an image  $I$  of a playing card on the rear projection screen  $W$ . The image on this screen (Polacoat Lenscreen) was visible to  $O$  as a white playing card with black numbers and black clubs, with the playing card ( $R$ ) apparently suspended directly in front of himself at a distance  $D'$  and having a perceived width  $S'$ . The visual angle ( $\theta$ ) of the width of the card was inversely related to the distance  $D_T$  of the transparency from the point source.<sup>12</sup> The transparency and baffle were mounted on a small cart that could be moved toward or away from  $P$  at a constant speed along a track provided by an optical bench. The cart was moved by means of a constant-speed motor controlled by  $E$  or  $O$ , as required. Calibration related the position of the cart along the track to the visual angle  $\theta$  of the image of the card on the screen, or to the distance  $D$  from  $O$  at which a normal-sized playing card would have to be placed to subtend the visual angle  $\theta$ . Throughout this study, the visual angle  $\theta$  of the image of the playing card on the screen will be referred to as the visual angle of the playing card.

The viewing position of  $O$  contained an adjustable chair and an adjustable head and chin rest together with a pair of eyepieces. The view-

ing was monocular (right eye only) with the left eyepiece occluded. To the left of the viewing position was a light adaptation surface ( $L$  in Figure 1) with a brightness of 15 ft-L. This surface was shaped to fit around the nose of  $O$  so as to present a homogeneous visual field. The visual field was homogeneous in order to avoid producing a comparison field with which  $O$  could compare the subsequently presented stimuli.<sup>7</sup> Microswitches were mounted on both the adaptation apparatus and the viewing position for the playing card in order to insure that no stimulus was visible except when  $O$ 's head was properly positioned in the apparatus.

A kinesthetic standard, invisible to  $O$ , was provided to assist  $O$  in judging the perceived distance ( $D'$ ) of the playing card. For this purpose, two round stationary rods that  $O$  could grasp, one in each hand, were located (one to the right and the other to the left of the viewing position) at approximately the level of  $O$ 's chest. On top of each rod was a small peg. The distance between pegs was 3 feet. Also, two square posts approximately 6 inches high and  $\frac{3}{8}$  inch wide were located near the viewing position at about the height of  $O$ 's waist. These posts were used in the measurement of the perceived width ( $S'$ ) of the playing card. The left post was stationary, while the right post could be moved to the right or the left by  $O$  until the distance between the posts was equal to the perceived width. The viewing position, the two rods and posts, and the light-adaptation apparatus were

all contained in a compartment covered with black cloth to completely exclude any extraneous light from reaching  $O$ 's eye. At the viewing position, the eyepiece in front of  $O$ 's right eye contained an aperture 1.3 cm in diameter. No portion of this eyepiece or aperture was visible to  $O$  while viewing the playing card.

Two sets of static situations were used. The angular size of the width of the cards was  $7.3^\circ$ ,  $3.9^\circ$ , and  $1.9^\circ$  in the set presented first and  $5.9^\circ$ ,  $2.3^\circ$ , and  $1.4^\circ$  in the set presented second. These angular sizes correspond to normal playing cards located 1.48, 2.79, and 5.71 and at 1.80, 4.72, and 7.68 feet from  $O$ , respectively. Two sets of dynamic situations were also used with the same  $O$ 's. At the position of the right round rod, a small plastic ring was located. When  $O$  pressed the plastic ring, a microswitch was activated that, by controlling the motor in the dynamic adjustments, changed the position of the cart on the track in either direction and, hence, controlled the visual angle and the perceived distance of the playing card. To prevent  $O$  from basing his distance judgments on the length of time he pressed the ring in the dynamic situations, six different starting positions (visual angles of the card) were used. These were  $7.3^\circ$ ,  $6.3^\circ$ ,  $4.7^\circ$ ,  $3.1^\circ$ ,  $1.5^\circ$ , and  $0.8^\circ$ . It is readily demonstrated that the constant track speed in the point-source apparatus produced a rate of change of visual angle proportional to that produced by a playing card also moving with a constant speed.<sup>12</sup> In the present study, the dynamic stimulus always was equivalent to a normal playing card moving directly toward or away from  $O$  at a constant speed of 7.7 cm/sec.

For both the static and dynamic situations, care was taken that no object was ever visible except the playing card. The luminance of the playing card as viewed from the  $O$ 's position always was 0.14 ft-L.

*B. Comparison Field.* A well-structured visual field (visual alley of Figure 1) was used with half the  $O$ 's during the second static situation. Since the well-structured field provided  $S'/\theta$  values that  $O$  could compare with the playing card, it is called a "comparison field" even though  $O$  was never instructed to make comparisons between the playing card and this field. The comparison field was monocularly visible to  $O$  (right eye only) through the partially transmitting, partially reflecting mirror  $M_1$  (Figure 1) only

when the lights above the alley were turned on, and an occluder at the front of the alley was raised. The floor of the alley, which was 4 feet wide and extended 48.7 feet from  $O$ , contained an assortment of familiar objects (but no playing cards) and was covered with light- and dark-grey rectangles (18 inches long by 9 inches wide). The walls and back of the alley were formed by white curtains. In order for the portion of the alley close to  $O$  to be visible, a ramp was constructed to slope upward from the alley floor beginning at a distance of 5.7 feet and extending to the position of  $M_1$  (0.7 feet from  $O$ ). White objects to be used with the distance judgments were identified by letters or numbers and were placed along the alley floor at 3, 7, 12, and 22 feet from  $O$ . When size judgments were required in the comparison field, blue rectangles whose widths subtended a constant visual angle of  $1.2^\circ$  were successively placed at each of these same distances.

*C. Calibration Situation.* The methods of using verbal reports to indicate perceived distance and the hand-adjustment apparatus to indicate perceived size were evaluated by using a full-cue visual field called the calibration situation. For this purpose, the curtains at the far end of the alley were pushed aside, and a viewing position consisting of a chin rest was positioned directly above this end of the alley. Numbered rectangles, to be used with the verbal reports, were located at 2, 5, 8, 14, 20, and 26 feet along the alley from the viewing position. Blue rectangles, 1, 2, 4, 8, and 15 inches wide, to be used with a hand-adjustment apparatus, similar to that described previously, were presented one at a time at a constant distance of 3.5 feet. The perceived width of a normal-sized playing card (king of hearts) also presented at 3.5 feet from  $O$  was measured at the end of the calibration series. The calibration situation represents the situation with the most complete size and distance cues and is the only portion of the experiment in which binocular observation was used.

### III. Observers.

The  $O$ 's of this study were 60 men between the ages of 18 and 40 who had at least a high-school education, who were naive with respect to the purpose of the study, and who had an uncorrected visual acuity of at least 20/20 in each eye as measured with the Bausch and Lomb Orthorator at both the near and far points.

#### IV. Procedure.

A. *First Set of Static Situations.* In both the first and second sets of static situations, every *O* was successively presented with each of three angular (retinal) sizes of the playing card. Each of the six possible orders of successive presentations of the three image sizes was used with a different group of 10 *O*'s with the result that each angular size was presented first equally often. Thus, 20 of the *O*'s were first presented with the largest, 20 of the *O*'s with the middle, and 20 of the *O*'s with the smallest of the three retinal sizes used in each set of static situations.

Before the experimental conditions were presented, the observation booth was lighted, and *O* was instructed in the use of the round rods and square posts and was given practice in moving his head between the viewing position and the light adaptation apparatus. *O* was informed that the distance between the two pegs, one on the top of each rod, was 3 feet. In an attempt to isolate *O* from previous stimulation that could act as a comparison field, the light in the observation booth was turned off and *O* remained in total darkness for 10 minutes. After this period, *O* positioned his head in the light-adaptation device, which was activated for 30 seconds. Following the light adaptation, *O* positioned his head in the viewing position and observed the playing card suspended in front of himself in an otherwise black field of view. While grasping the round rods with one thumb on each peg, *O* verbally estimated the distance that the playing card seemed to be from himself in feet or in inches or in a combination of both. The two square posts were used by *O* to indicate perceived width ( $S'$ ). For this purpose, *O* grasped the square posts, one in each hand and moved the right post laterally until the distance between the inner surfaces of the posts seemed to be the same as the width (left to right extent) that he saw in the playing card. Since the posts were not visible, the adjustment was made kinesthetically. One adjustment started with the square posts far apart and the other with the square posts together. Throughout this experiment, the average of these two adjustments is a width score. At no time either during or between any of these judgments were the square posts or the round rods or any other portion of the apparatus other than the playing card visible to *O*. Following the distance and size judgments

made with respect to the first presentation of the playing card, a shutter was closed, occluding *O*'s view of the card; a different visual size of the playing card was produced; the shutter was opened, and another distance report was obtained. This procedure was repeated with the third visual angle of the playing card. In the first set of static situations, the only width score ( $S'$ ) that was obtained followed the first presentation, whereas  $D'$  was obtained for all three static presentations. The *O* was light-adapted immediately prior to the first presentation only. Thirty to 60 seconds usually occurred between presentations throughout the experiment.

B. *First Set of Dynamic Situations.* Upon completing the judgments involving the first set of static situations, *O* was light-adapted and presented with the first set of dynamic situations. Before permitting *O* to view the card, *E* adjusted the playing card to the required starting position for the particular dynamic presentation and threw the switch that allowed *O* to adjust the playing card in apparent depth. While grasping the round rods and viewing the playing card (monocularly), *O* adjusted the visual angle of the image on the screen until the card appeared to be at a distance from himself that was equal to the specified multiple of one, two, or three times the distance between the pegs on the two rods. Each of the 60 *O*'s was given each multiple twice in random order with the restriction that the order of conditions throughout the first set of static and dynamic situations, was duplicated with half the *O*'s. The resulting six distance adjustments were randomly paired with the six starting sizes with the restriction that a particular starting size was paired with a particular task (multiple) equally often. The starting sizes were equivalent to a real playing card 1.48, 1.71, 2.30, 3.51, 7.15, and 13.16 feet from *O*. Since the *O*'s were aware that the distance between the round rods was 3 feet, veridical depth adjustments of the cards would have been adjustments equivalent to 3, 6, 9 feet. Two size (width) adjustments were completed only after *O* had finished the six dynamic distance adjustments.

C. *Second Set of Static Situations.* The procedure for the second set of static situations was identical to that for the first set except that a different set of three image sizes was used, the two size judgments did not occur until the completion of all the distance judgments, and half

of the *O*'s in the second set viewed the comparison alley for 30 seconds prior to each static presentation. The orders of presenting the three card sizes to the group of *O*'s viewing the comparison field were duplicated for the *O*'s who saw only the images of the playing card.

D. *Second Set of Dynamic Situations.* The procedure for the second set of dynamic situations was identical to that of the first except that the same *O*'s who had previously viewed the comparison alley in the second set of static situations made size and distance judgments with respect to objects in the comparison alley prior to being presented with the second set of dynamic situations. With half of the *O*'s, the size judgments in the comparison alley were made before the distance judgments. With the remaining *O*'s this order was reversed.

E. *Comparison Field and Calibration Situation.* The sizes and distances to be judged in the comparison field (with 30 *O*'s) were presented in random orders with size judgments preceding and following the distance judgments equally often. The calibration situation was always presented last for all 60 *O*'s. The sizes and distances to be judged in the calibration situation were presented in random orders (except for the normal-sized king of hearts, which was always presented last). As in the case of the static and dynamic situations, distance judgments in the comparison field and calibration situation were made verbally, and size judgments were made kinesthetically.

After finishing the experiment, each *O* was questioned as to the manner in which he made his size and distance judgments in the experiment.

## V. Results.

As indicated by the question period that fol-

lowed the *O*'s completion of the experiment, six *O*'s made angular size rather than apparent size adjustments during the first part or during most of the experiment. It was as though these six *O*'s imagined a frontal plane either at the distance of their hands or at some other distance and judged the width of the playing card as angularly projected on that plane. Two other *O*'s, despite the instructions, adjusted the movable rod of the hand-adjustment apparatus with respect to the right edge of the card without regard to the resulting separation between the rods. Since "phenomenal" judgments were required in order to test Equation (2), the results from these eight *O*'s were omitted from the data, and eight other *O*'s were used in their place.

A. *Results From the First and Second Set of Static Situations.* The results from the first set of static situations are given in Table 1. The  $\theta$  values are the visual angles subtended by the images of the playing card on the screen. The *D* values are the distances in centimeters at which a normal-sized playing card (5.7 cm wide) would have to be placed to subtend the visual angle  $\theta$ . The *D'* values are the average perceived distances of the playing card obtained from the verbal reports converted to centimeters, with each average based on 20 verbal reports. The values of *D/S* were found by dividing *D* by 5.7 cm., the width of a normal-sized playing card. Each *D'/S'* value in Table 1 is the average of 20 values of *D'/S'*, one from each *O*, with each *S'* the mean of the two size adjustments made by a particular *O*. The standard deviations ( $\sigma$ ) of *D'* and *D'/S'* indicate the variability between *O*'s in these types of scores. The average value of *S'* was 8.6 cm for the first set of static situations, with a standard deviation of 8.4 cm. One *O* in the first static situation was unable to separate

TABLE 1. Average results and standard deviations ( $\sigma$ ) in centimeters from the first set of static situations. *S'* and *D'* are the perceived width and the perceived distance associated with a playing card of physical width *S*, located at a simulated distance *D*, in centimeters, and subtending a visual angle  $\theta$ .

	First presentation			Second presentation			Third presentation		
	$\theta$	7.3°	3.9°	1.9°	7.3°	3.9°	1.9°	7.3°	3.9°
<i>D</i>	45	85	174	45	85	174	45	85	174
Mean <i>D'</i>	125	116	116	32	84	263	45	108	194
$\sigma$ of <i>D'</i>	227	125	65	17	72	261	64	106	144
<i>D/S</i>	7.8	14.8	30.4	7.8	14.8	30.4	7.8	14.8	30.4
Mean <i>D'/S'</i>	8.2	16.6	17.6	5.4	11.0	30.6	5.9	13.6	25.9
$\sigma$ of <i>D'/S'</i>	5.4	9.3	11.3	3.8	8.5	21.0	4.2	11.3	10.8

the posts sufficiently far to indicate the perceived width of the card. This  $O$  adjusted the posts to one-half the perceived width, and consequently the adjustments from this  $O$  were doubled to determine his value of  $S'$ .

Of particular interest in Table 1 are the means resulting from the first presentations of the three different retinal sizes ( $\theta$ ) with each size first presented to a different group of 20  $O$ s. These are the only data of the study that, by meeting the requirements discussed previously, are designed to provide valid measures of perceived absolute distance  $D'$  for use in testing Equations (1) and (2). It will be seen from Table 1 that, contrary to Equation (1), the average values of  $D'$  in the first presentation are not only disproportionate to  $D$ , but fail to increase with increases in  $D$ . It seems, however, that a few  $O$ 's saw the playing card in the first presentation as both distant and large. Two of these  $O$ 's had been first presented with the large value of  $\theta$  and two  $O$ 's with each of the smaller values of  $\theta$ . When these four deviant values of  $D'$  were removed, the resulting  $D'$  values were 54, 90, and 107 cm for  $D$  values of 45, 85, and 174 cm, respectively. The standard deviations computed from the distributions of  $D'$  with these deviated values removed were reduced from the values shown in Table 1 for the first presentation to 40, 48, and 55 cm, respectively. The average values of  $D'/S'$  in Table 1 associated with the largest and intermediate values of  $\theta$  are similar to the expected values of  $D'/S'$  and, therefore, support Equation (2), but the average  $D'/S'$  resulting from the smallest  $\theta$  does not. Throughout this study, half the degrees of freedom (df) were used whenever the distributions were heterogeneous in variance and involved equal numbers ( $N$ ) or  $O$ 's. In the case of heterogeneity and unequal  $N$ 's, the value of  $t$  required for significance was calculated<sup>13</sup> and compared with the experimentally obtained value. Using the  $t$  test, the 8.2 value of  $D'/S'$  obtained from the largest retinal size was significantly different beyond the 0.01 level from both the 16.6 and 17.6 values obtained from the two smaller sizes ( $t=3.35$ ,  $df=19$ , and  $3.48$ ,  $df=19$ , respectively) at the 0.05 level. A comparison of the values of  $D'$  and  $D'/S'$  in Table 1 indicates the merit of measuring  $S'$  as well as  $D'$  in testing whether familiar size is a determiner of perceived absolute distance. It seems, considering the  $D'/S'$  values from the first

presentation, that the combination of the perceived size and the visual angle of the playing card was a determiner of perceived absolute distance for the two larger values of  $\theta$  ( $D$  up to about 3 feet) but not for the smallest value of  $\theta$  ( $D$  approximately 6 feet).

The results from the second and third presentations in Table 1 are generally more in agreement both Equations (1) and (2) than are the results from the first presentation. The effect of successive presentations is to make the  $D'$  and  $D'/S'$  scores more like  $D$  and  $D/S$ . If  $D'=D$  and  $D'/S'=D/S$ , it would be concluded that  $O$  perceived that a normal-sized card was located at the distances ( $D$ ) given in Table 1. Such perceptions might be termed veridical distance perceptions. It seems, from the averages of Table 1, that to whatever extent perceptual veridicality was approximated on the first presentations, it occurred only with the two largest image sizes, and perceptual veridicality with respect to the smallest image size was approached only as a result of successive presentations. It should be noted that intersubject variability tends to be large, so that perceptual veridicality, when it occurs in Table 1, should be regarded as an average rather than as an individual achievement.

As shown in Table 1, the average  $D'/S'$  obtained from the smallest image size of the playing card increased from the 17.6 value obtained in the first presentation to 30.6 in the second presentation and 25.9 in the third presentation. Each of these increases was significant beyond the 0.025 level ( $t=2.43$ ,  $df=19$ , and  $2.37$ ,  $df=38$ , respectively). These changes can be explained in terms of relational judgments occurring over time. For the purpose of this explanation, it is convenient to regard  $D'/S'$  as a perceived distance corrected for individual differences in perceived size. Furthermore, it is useful to consider two factors as determining this perceived distance (per  $S'$ ) for any image size. The first factor is the tendency for  $O$  to perceive the card as being located at a particular distance from himself regardless of the perceived distance of this card with respect to the prior presentations of the card in the experiment. This might be called the absolute localization effect. The second factor is the tendency to perceive the card at a particular distance as determined by the distance cues between the card and previous

presentations of the card. This might be termed the relative localization effect. Both the absolute and relative localization effects can be present to determine a particular perceived position of the card. Clearly, as discussed above, in the case of the second or third presentation of the smallest image size, the relative localization effect determined the perceived position of the card. The prior presentation of the two largest image sizes (which in general were most correctly perceived with respect to distance) increased the veridicality of the perceived distance associated with subsequent presentations of the smallest image size. Conversely, however, the erroneously perceived distance associated with the first presentation of the smallest image size might have reduced the veridicality of the perceived distances associated with subsequent presentations of the larger image sizes. Indeed, it is found that the  $D'/S'$  resulting from the intermediate image size ( $\theta=3.9^\circ$ ) is 16.6 when this size was presented first and 7.9 when it was immediately preceded by the presentation of the smallest image size. This difference is significant beyond the 0.01 level with a one-tailed test (experimentally obtained  $t=3.34$ , calculated  $t_{.01}=2.64$ ,  $N=10$  and 20). Similarly, the average  $D'/S'$  from the largest image size ( $7.3^\circ$ ) was 8.2 when it was presented first and 4.5 when it was preceded by the presentation of the smallest image size. Using  $\alpha$  one-tailed test, this difference is significant beyond the 0.05 level ( $t=2.20$ ,  $df=28$ ). It seems that the relative localization effects resulting from relative size cues occurring between

successive presentations are important in determining perceived position even though (as is the case with the larger image sizes) the subsequent presentations would ordinarily be localized somewhat by familiar size as a cue to absolute distance. It follows that  $O$ 's will tend to use relative size cues between successive presentations to determine perceived distance even in circumstances where absolute localization effects would otherwise occur.

The results from the second static situation both for the condition in which the monocularly viewed alley (comparison field) containing many objects did or did not precede each presentation of the card are given in Table 2. Each of the means and standard deviations in Table 2 is based upon 10 scores, one from each  $O$ . The notation of Table 2 is the same as that of Table 1. According to Table 2, no obvious effect upon the subsequently perceived distances of the playing card seems to have occurred as a consequence of the interpolation of the comparison field. It will be noted that the standard deviations of  $D'$  and  $D'/S'$  in Table 2 show little tendency to decrease with increasing numbers of presentations. Large and continuing observer differences are characteristic of Table 2 as of Table 1.

B. *Results From the First and Second Sets of Dynamic Situations.* The task of  $O$  in the dynamic situations was to adjust the playing card until it appeared at 3, 6, or 9 feet from himself. The range of possible adjustments of visual angle provided by the apparatus was from  $0.8^\circ$  to  $7.3^\circ$ . It was found in the dynamic situations

TABLE 2. Average results and standard deviations ( $\sigma$ ) in centimeters from the second set of static situations.  $S'$  and  $D'$  are the perceived width and perceived distance associated with a playing card of physical width  $S$ , located at a simulated distance  $D$ , in centimeters, and subtending a visual angle  $\theta$ .

	First presentation			Second presentation			Third presentation		
$\theta$	$5.9^\circ$	$2.3^\circ$	$1.4^\circ$	$5.9^\circ$	$2.3^\circ$	$1.4^\circ$	$5.9^\circ$	$2.3^\circ$	$1.4^\circ$
$D$	55	144	234	55	144	234	55	144	234
$D/S$	9.6	25.3	40.9	9.6	25.3	40.9	9.6	25.3	40.9
<i>No comparison field</i>									
$D'$	56	155	200	63	116	247	49	140	265
$\sigma$ of $D'$	24.9	105.2	80.8	40.4	48.3	97.1	43.7	45.2	65.9
$D'/S'$	10.3	18.5	31.1	10.9	19.5	29.2	3.5	25.8	55.4
$\sigma$ of $D'/S'$	4.5	14.8	18.5	5.8	15.2	9.7	1.6	8.1	28.8
<i>Comparison field</i>									
$D'$	58	201	183	46	137	326	75	122	197
$\sigma$ of $D'$	25.7	254.2	66.0	23.2	49.2	320.4	50.5	40.6	40.9
$D'/S'$	14.1	20.4	30.7	8.8	28.0	43.0	9.6	26.3	43.4
$\sigma$ of $D'/S'$	9.8	8.7	9.0	5.3	14.3	26.6	6.1	17.8	25.7

that for five  $O$ 's the visual angle of the playing card could not be made sufficiently large so that the card appeared to  $O$  to be at 3 feet. For four other  $O$ 's, the visual angle could not be made sufficiently small so that the card appeared to  $O$  to be at 9 feet. In order to permit comparisons between the different dynamic conditions, none of the data from these  $O$ 's was used in the analysis of the results from either the first or second set of dynamic situations. The remaining 51  $O$ 's were divided into two groups, depending upon whether later in the experiment the  $O$ 's were or were not presented with a com-

parison field. The reason for this division will become clear when the results from the second set of dynamic situations are considered. Results from the 27  $O$ 's who later were presented with the comparison field and from the 24  $O$ 's who were never presented with the comparison field are shown in Figures 2a and 2b, respectively. The values of  $\theta$  used in Figure 2 are the visual angles, expressed in radians, of the image of the playing card adjusted by  $O$  in order to produce the perceived distance of 3, 6, or 9 feet (91, 183, or 274 cm, respectively) given on the abscissa. A value of  $S'$  is the

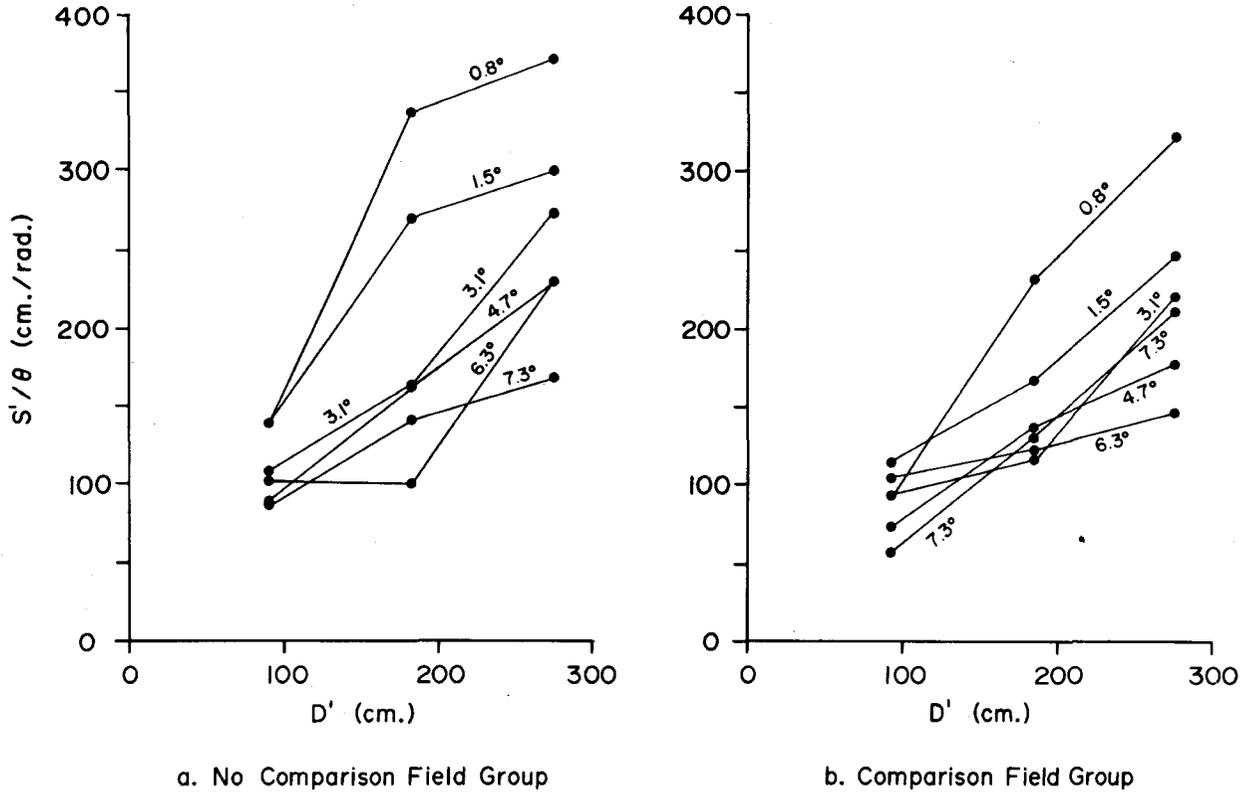


FIGURE 2. The relation between perceived size  $S'$  (per unit of retinal size  $\theta$ ) and perceived distance  $D'$ , for two groups of  $O$ 's in the first set of dynamic situations.

mean of the two width judgments that followed the completion of the distance judgments in the first set of dynamic conditions. The values of  $S'/\theta$  used on the ordinate are the means of distributions of  $S'/\theta$  with  $S'$  expressed in centimeters. It became evident in the analysis of the data that starting size was an important variable in determining the final adjustments in the dynamic situations. This was tested statistically by computing for each  $O$  the difference between the results from the first dynamic situ-

ation when using a smaller rather than a larger starting size for each of the three distance tasks. The resulting mean difference in  $S'/\theta$  (averaged over the three distance tasks and all 51  $O$ 's) was 216 cm/rad with the smaller of the pair of starting sizes producing the greater value. This difference was significant beyond the 0.01 level of confidence ( $t=7.72$ ,  $df=50$ ). Therefore, the data from the different starting sizes are presented separately in Figure 2. The number of  $O$ 's involved in each data point in Figure 2

varied from 5 to 10. The numbers associated with each of the curves of Figure 2 represent the visual angle of the starting size of the playing card expressed in degrees. According to the size-distance hypothesis of Equation (2), all the data curves of Figure 2 should be the same curve passing through the origin with a constant slope ( $K$ ). In general, the curves of Figure 2 if extended would approximately pass through the origin. In agreement with the above analysis, however, the smaller starting sizes ( $0.8^\circ$  and  $1.5^\circ$ ) tended to require larger values of  $S'/\theta$  in order to achieve the same  $D'$  than were required when the larger starting sizes ( $3.1^\circ$  to  $7.3^\circ$ ) were used. No clear differences seem to be present between the curves resulting from the larger starting sizes. The differences between the data curves from the largest and smallest group of starting sizes may be explained in a manner similar in principle to that used in explaining the changes in the results occurring between successive presentations in the first set of static situ-

ations. For this purpose, the adjustment of the angular size of the card by  $O$  may be considered as consisting of a series of distance judgments made with respect to a rapid succession of presentations, with each judgment in the series made relative to the immediately preceding presentation. It is possible that interaction effects resulting from such a series of judgments may accumulate in one direction or the other as a function of the starting size. Since, according to Figure 2, the  $S'/\theta$  value necessary to achieve a particular  $D'$  was usually greater for smaller rather than larger starting sizes, it can be concluded in general that, for a given  $S'/\theta$ , the image appeared to be closer when it was preceded by the smaller rather than the larger starting sizes. That this seems consistent with the direction of the results obtained in the static situations is shown in Figure 3, in which the data from the static situations are presented in the same form as the results from the dynamic situations shown in Figure 2. Each data curve in Figure 3 gives

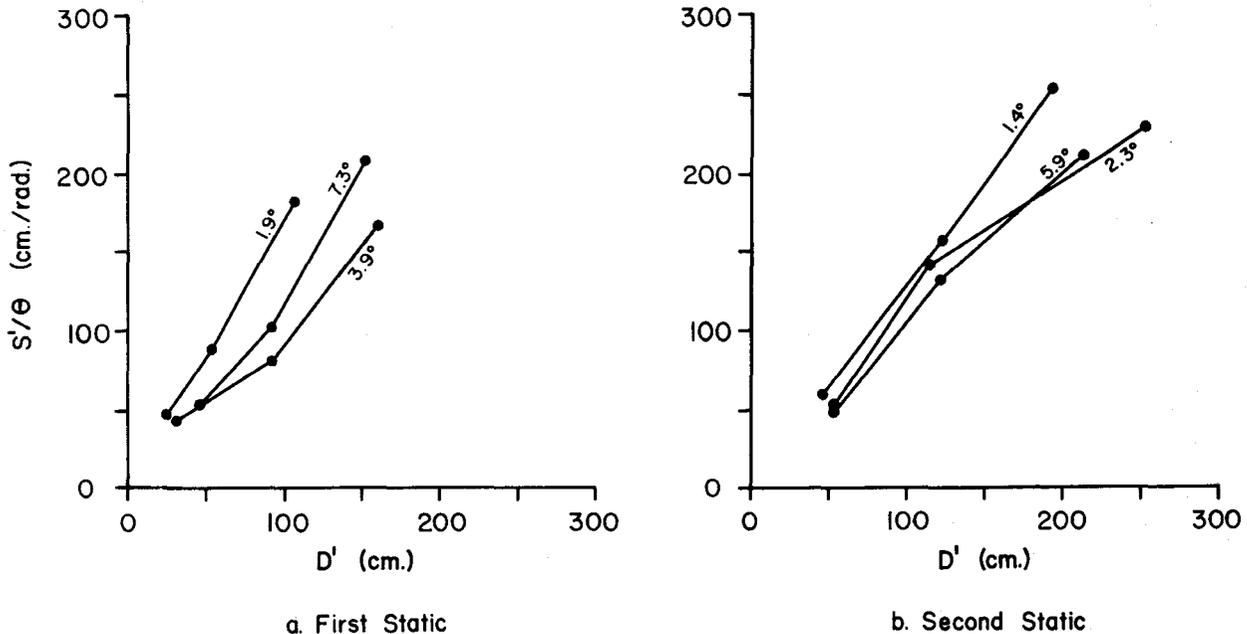


FIGURE 3. The relation between perceived size  $S'$  (per unit of retinal size  $\theta$ ) and perceived distance  $D'$ , for the first and second set of static situations.

the results obtained from all three retinal sizes for the 20  $O$ 's in the first or second set of static presentations who started their series of judgments with a playing card of the indicated angular size ( $1.4^\circ$ ,  $2.3^\circ$ , or  $5.9^\circ$ ). In Figure 3, the smallest starting sizes in both the first and second set of static situations ( $1.9^\circ$  and  $1.4^\circ$ ) tended

to result in smaller values of  $D'$  per value of  $S'/\theta$  than did the largest starting sizes ( $7.3^\circ$  and  $5.0^\circ$ ). Also, in agreement with Figure 2, considering Figures 3a and 3b together, no consistent differentiation occurred between the middle starting sizes ( $3.9^\circ$  and  $2.3^\circ$ ) and the largest starting sizes ( $7.3^\circ$  and  $5.9^\circ$ ).

Another possible explanation of the difference obtained between the large and small starting sizes shown in Figure 2 is in terms of an anticipatory response; i.e., a tendency for  $O$  to stop the apparent movement before reaching the appropriate perceived position. Against this explanation is (1) the large differences between some of the curves of Figure 2, (2) the similar effects that occurred in the static situations (Figure 3), and (3) the consistent variation in the effect of starting size with perceived distance (task) and not with the magnitude of the adjustment from

the starting position. Both the first set of static and the first set of dynamic situations provide strong evidence for the perceptual interaction of successive stimuli whether these stimuli are changing discretely or continuously.

The average results from the 51  $O$ 's in the second set of dynamic situations are shown in Figure 4. Figure 4a contains the results from 27  $O$ 's who, prior to the dynamic adjustments, made size and distance judgments with the comparison field, while Figure 4b contains the results from the 24  $O$ 's who never were presented with

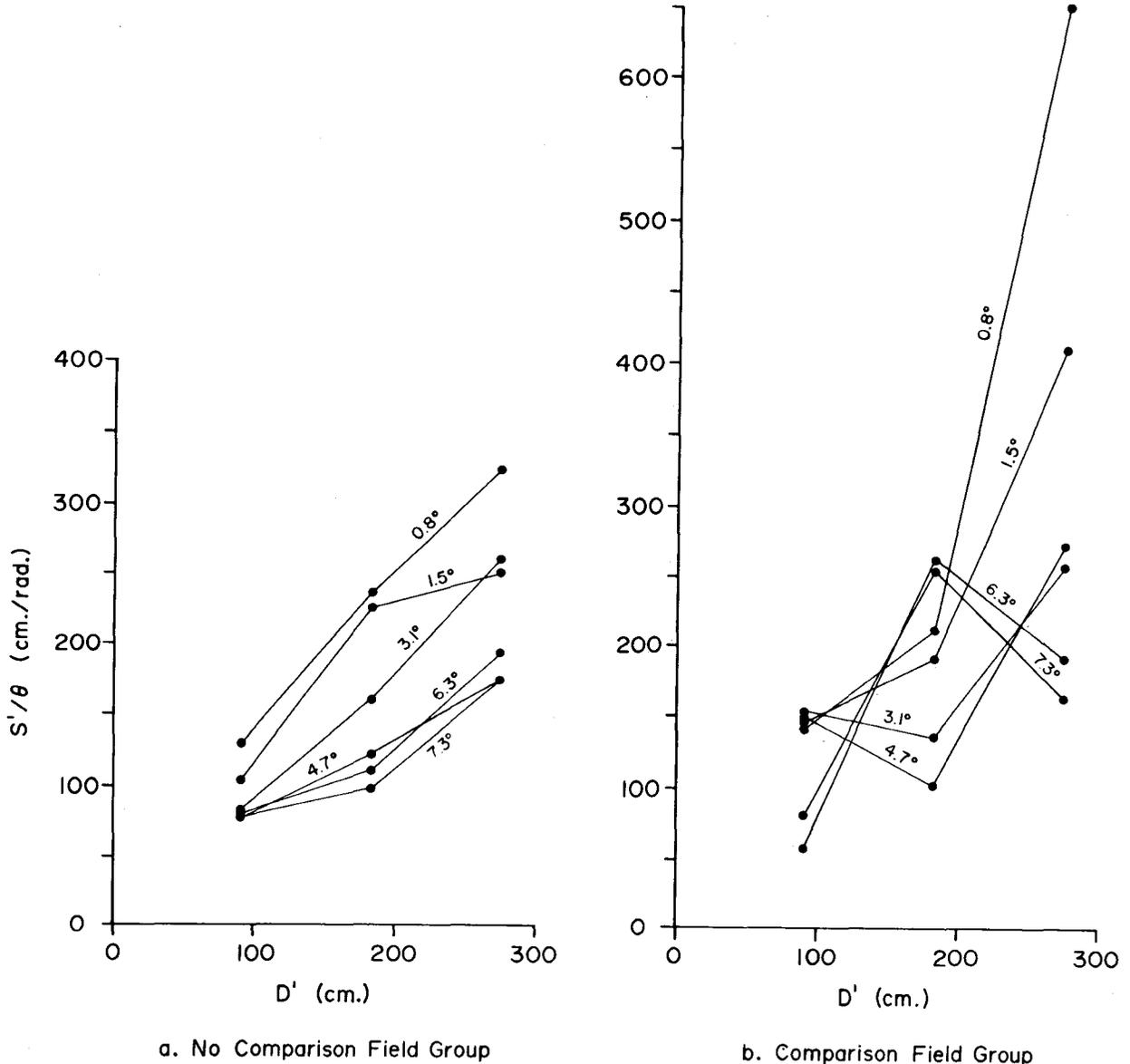


FIGURE 4. The relation between perceived size  $S'$  (per unit of retinal size  $\theta$ ) and perceived distance  $D'$ , in the second set of dynamic situations for the same two groups of  $O$ 's used in Figure 1. The "comparison-field group" made judgments of perceived size and distance in the comparison field immediately prior to the judgments in the second dynamic situation, whereas the "no comparison field group" did not.

the comparison field. The data are presented separately for the six values of starting size. Although Figure 4a is much like Figure 2a, Figure 4b differs markedly from Figure 2b. It appears that the experience with the comparison field affected the subsequent judgments with respect to the playing card. This occurred even though the  $O$ , in adjusting the apparent distance of the card, was not given the task of judging the card with respect to the comparison field. The major effect of the comparison field in this portion of the experiment seems to have been the disruption of the generally orderly displacements of the curves resulting from the different starting positions. This disruption did not seem to occur with the static situations, as would be indicated if the data curves from the static situations were plotted separately for the groups that did or did not experience the comparison field. The significance of the disruption in the dynamic situations was calculated by using the variability of the distributions described previously, in which the results from the smaller of the two starting sizes used with a particular distance adjustment was subtracted from the results for the larger of the two starting sizes, and the differences were averaged over the three distance tasks for all 51  $O$ 's. The difference in this variability between the first and second sets of dynamic situations is statistically significant for

those  $O$ 's who experienced the comparison field ( $F=3.34$ ,  $df=26,26$ ) but not for those  $O$ 's who did not ( $F=1.93$ ,  $df=23,23$ ). The judgments made in the comparison field had a significant effect upon subsequent judgments made in the dynamic situations.

The adjustment by  $O$  of the size of the image of the playing card on the screen in the dynamic situations can be expressed in terms of the distance ( $D$ ) at which a normal-sized card (5.7 cm wide) would have to be located in order to subtend that visual angle. The results expressed in this fashion give the distances that would have been adjusted if a normal-sized card of constant physical size had actually been moved in physical depth. The average values of  $D$  from the first and the second set of dynamic situations for each of the six starting sizes are given in Table 3. The average perceived width ( $S'$ ) of the playing card as determined by the kinesthetic (hand) adjustments was 6.2 cm for the first and 7.0 cm for the second dynamic situation. In agreement with Figures 2, 3, and 4, the effect of starting sizes as shown in Table 3 by the increase in  $D$  with increases in starting sizes is clear.

*C. Results from the Comparison Field and Calibration Situation.* Table 4 gives the results from the comparison and calibration fields. Each mean and standard deviation is based on 30 scores in the case of the comparison field and 60 scores

TABLE 3. Average results  $D$  and standard deviations ( $\sigma$ ) in centimeters from adjusting the playing card to a perceived distance of 3, 6, or 9 feet for six values of starting sizes or starting distances with  $N$  observers.

First set of dynamic situations										
Starting size (degrees)	Starting distance (cm)	3 feet			6 feet			9 feet		
		$N$	$D$	$\sigma$	$N$	$D$	$\sigma$	$N$	$D$	$\sigma$
7.3	45	15	72	23	18	127	27	18	179	53
6.3	52	17	76	16	17	129	46	17	184	59
4.7	70	19	80	19	15	123	23	17	194	49
3.1	107	17	92	18	16	149	25	18	205	62
1.5	218	16	124	36	17	183	49	18	259	54
0.8	401	18	128	27	19	228	77	14	310	55

Second set of dynamic situations										
Starting size (degrees)	Starting distance (cm)	3 feet			6 feet			9 feet		
		$N$	$D$	$\sigma$	$N$	$D$	$\sigma$	$N$	$D$	$\sigma$
7.3	45	18	76	38	17	110	32	16	181	52
6.3	52	16	66	16	19	123	26	16	182	55
4.7	70	19	81	17	15	115	26	17	176	46
3.1	107	17	95	16	16	139	33	18	210	61
1.5	218	17	107	24	16	182	30	18	258	40
0.8	401	15	114	25	19	211	43	17	328	57

of judgments will differ, depending on a number of factors, such as the temporal characteristics of the sequence and the range of stimuli sizes used. Therefore, it is unlikely that Equation (2) or any similar equation is capable of describing the perceived distance resulting from familiar size under a wide variety of conditions.

*D. Effect of Comparison Fields.* The repeated interpolation of the comparison field in the second set of static presentations had no obvious effect upon the judgments of the perceived distances of the playing card; however, the completion of size and distance judgments in the comparison field prior to the presentation of the second set of dynamic situations had a disruptive effect upon the judgments. Several factors can be considered that possibly might have been important in determining the effect of the comparison field on subsequent judgments of the playing card. In view of the significance of sequential relations in this experiment, it is clear that the comparison field must be considered as only one of a number of visual stimuli inserted into an ongoing series of relational judgments of distance. As such, the comparison field and the previous series of judgments would be competitive in terms of influencing the subsequent judgments. In order for the comparison field to have an influence different from that of the previous series the  $K$  value of the comparison field and the previous series should differ. That this is indeed the case can be seen by comparing the slope of the curves of Figures 2 and 3 with the slope that would result from plotting in a similar manner the comparison field data of Table 4. It might be reasonable to expect that the effect of the comparison field upon the subsequent judgments would be greater than that of the previous series because it was temporarily more adjacent to the subsequent judgments. A factor that might, however, reduce the influence of the comparison field relative to that of the prior series is that playing cards were used in the prior series and in the subsequent judgments but not in the comparison field. Perhaps the disruptive effect of the interpolated comparison field shown in Figure 4b is a consequence of the competitive effects of the prior series relative to that of the comparison field.

## VII. Summary.

The relation between the retinal size of a familiar object and its perceived distance was

studied using a point-source system of projection to produce an image of a ten-of-clubs playing card in an otherwise completely dark visual field. Both static (stationary) and dynamic (moving) presentations of the playing card were used. The  $O$ 's made size and distance judgments with respect to image sizes equivalent to a normal-sized playing card at 45, 85, and 174 cm with the first set and 55, 144, and 234 cm with the second set of static presentations. The image size that was presented first in each set of static situations was different for each of the three groups of 20  $O$ 's. The distance judgments consisted of verbal reports, and the size judgments were made kinesthetically. In two sets of dynamic situations, the  $O$ 's adjusted the size of the image of the playing card until the card appeared to be at 3, 6, or 9 feet from themselves and made kinesthetic judgments of its apparent size. A visual field containing many objects (a comparison field) was presented following the first set of static or dynamic presentations for half the  $O$ 's. In the second static situation, the comparison field was viewed prior to each distance judgment. In the second dynamic situation, judgments of size and distance were completed in the comparison field prior to the dynamic judgments. Judgments of size and distance made at the end of the experiment in a full-cue situation indicated that the method of measuring size and distance used in the experiment was valid in that these measures were proportional to perceived size and distance.

The average results from the first presentations of the first set of static conditions (the initial presentations of the experiment) were not found to be significantly different when only the judgments of perceived distance are considered. When both the size and distance judgments are considered together, however, the largest image size of the cards was perceptually differentiated from each of the two smaller sizes, but not the two smaller sizes from each other. These results are interpreted to mean that perceived size as well as retinal size should be considered in predicting the perceived distance resulting from familiar objects. When considering the judgments made in the first set of static conditions, it was concluded that the distance judgments made with respect to successive presentations were dependent upon the prior presentations. It was a though the distance judgment, for example,

with respect to a second presentation was the sum of the perceived distance to the first presentation of the card plus the perceived depth between the two presentations. This view of the sequential effect of successive judgments was supported by the results from the dynamic adjustments in that the judgments associated with the dynamic situations were modified as a function of starting size.

The introduction of the comparison field seemed to have had no effect upon the second set of static judgments and to have had a disruptive effect upon the second set of dynamic adjustments. It is concluded that the effect of comparison fields must be understood as part of the total sequence of experimental presentations. The factors determining such sequential interactions require further study.

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