SIZE CUES AND THE ADJACENCY PRINCIPLE

63-28

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Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma. CARI Report 63-28 **SIZE CUES AND THE ADJACENT PRINCIPLE** by Walter C. Gogel

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2. Depth Perception
3. Size Cues

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ABSTRACT

The purpose of the present study was to apply the adjacency principle to the perception of relative depth from size cues. In agreement with the adjacency principle, it was found that the size cue between adjacent objects was more effective than the size cue between displaced objects in determining the perceived relative depth position of objects. An additional, although minor, factor concerned with task-set was tentatively identified as contributing to the perception of depth from size cues.

A recent report has identified a factor which has been demonstrated to be effective in the perceptual organization of the three-dimensional world (Gogel, 1963). This factor labeled the "adjacency principle" asserts that the perceived size or position of an object is determined by whatever size or distance cues are present between it and adjacent objects. The adjacency [illegible]nciple has been demonstrated mainly with [illegible] cue of binocular disparity. The [illegible] concerned with the application of the adjacency principle to size cues of relative depth. It is predicted from the adjacency principle that size cues to relative depth between adjacent rather than displaced objects are the size cues most effective in determining apparent depth position.

A schema for applying the adjacency principle to the perceived depth resulting from size cues is illustrated in Fig. 1. Figure 1a shows a top view of the physical position of three objects (A, B, and D) all at the same distance from the observer (*O*). The dashed lines in Fig 1a represent lines-of-sight (directions from *O* to the objects). It is clear that Object A is directionally closer to Object B than to Object D $(\varnothing_2 > \varnothing_1)$. The adjacency principle states that the apparent depth position of A (with respect to B and D) is determined mainly by whatever depth cues occur between A and B. The depth cues between A and D are considered to be of less importance than those between A and B in determining the apparent depth position of A.

In Fig. 1, Objects A, B, and D are similar objects with the visual angular size of A equal to that of D and with both A and D half the visual angular size of B. Therefore, according to the relative size cue, A and D should appear at the same distance as each other with both A and D appearing more distant than B. Thus, if all distance cues other than relative size were absent, Objects A and D should appear at the same distance behind Object B. The apparent depth positions of A, B, and D as they would be expected from the size cue are shown in Fig. 1b as A′, B′, and D′. Under the circumstances indicated by Fig. 1b, it cannot be determined whether the equality of visual angular size between A and D or the angular size difference between A and B was most significant in determining the apparent depth position of A. Therefore, the adjacency principle cannot be investigated by using the conditions illustrated by Fig. 1b.

In Fig. 1c, a situation is illustrated in which an additional object (Object C) has been introduced. Object C, as a consequence of the cue

[1] The author wishes to thank Henry W. Mertens, Frank L. Agee, Jr., and James C. Hester for their assistance in collecting and analyzing the data of this study.

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A schema for applying the adjacency principle to the perceived depth resulting from size cues is illustrated in Fig. 1. Figure 1a shows a top view of the physical position of three objects (A, B, and D) all at the same distance from the observer (O). The dashed lines in Fig 1a represent lines-of-sight (directions from O to the objects). It is clear that Object A is directionally closer to Object B than to Object D ($\varnothing_2 > \varnothing_1$). The adjacency principle states that the apparent depth position of A (with respect to B and D) is determined mainly by whatever depth cues occur between A and B. The depth cues between A and D are considered to be of less importance than those between A and B in determining the apparent depth position of A.

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of interposition, appears to be in front of Object B and behind Object D. The interposition cue generated by Object C is effective such that the introduction of C will cause B to appear more distant than D in spite of the visual size difference between B and D. Under these conditions, the adjacency principle can be investigated by measuring the apparent distance position of A. If A appears at A'_1 in Fig. 1c, the size cue to relative depth between A and B is dominant in determining the apparent distance position of A. However, if A appears at A'_2 in Fig. 1c, the size cue to relative depth between A and D is dominant in determining the apparent distance position of A. From the adjacency principle, it would be predicted that the apparent position of A is more nearly A'_1 than A'_2.

METHOD

Apparatus

A top view schematic drawing of the apparatus used in the experiment is shown in Fig. 2. A partially transmitting-partially reflecting mirror, labeled M in Fig. 2, (45.9 cm. wide by 31.9 cm. high) was oriented at 45° both with respect to two light-boxes L_1 and L_2 and with respect to *O*. The optical distance from the front surface of both light-boxes L_1 and L_2 to *O* was the same (305 cm.). Boxes L_1 and L_2 were fluorescent light sources with a diffusing glass as a front surface. Positive transparencies of normal-sized (5.7 cm. by 8.9 cm.) or double-sized (11.4 cm. by 17.8 cm.) seven-of-spades playing cards were fastened to the front sur-

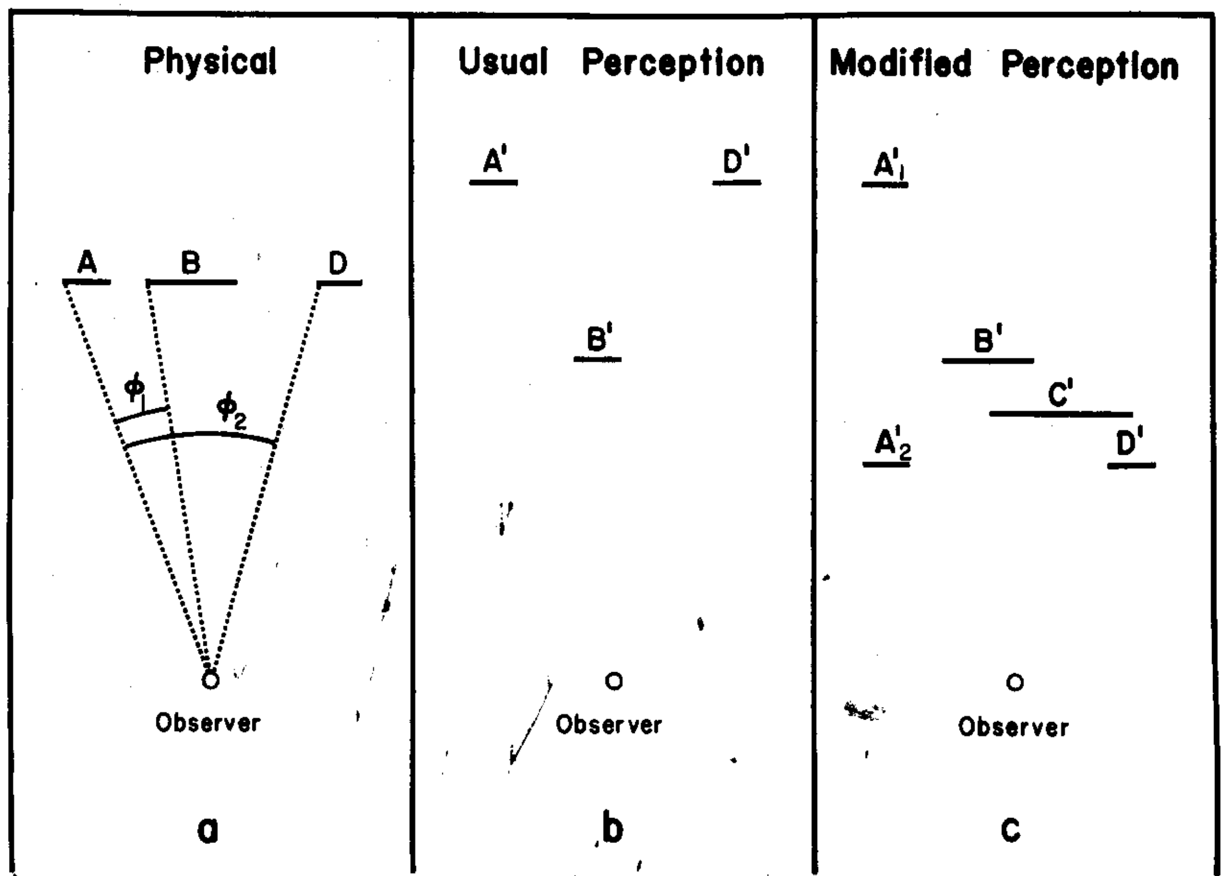

FIGURE 1. A schematic top view drawing illustrating a method of testing the application of the 'adjacency principle' to size cues to relative depth.

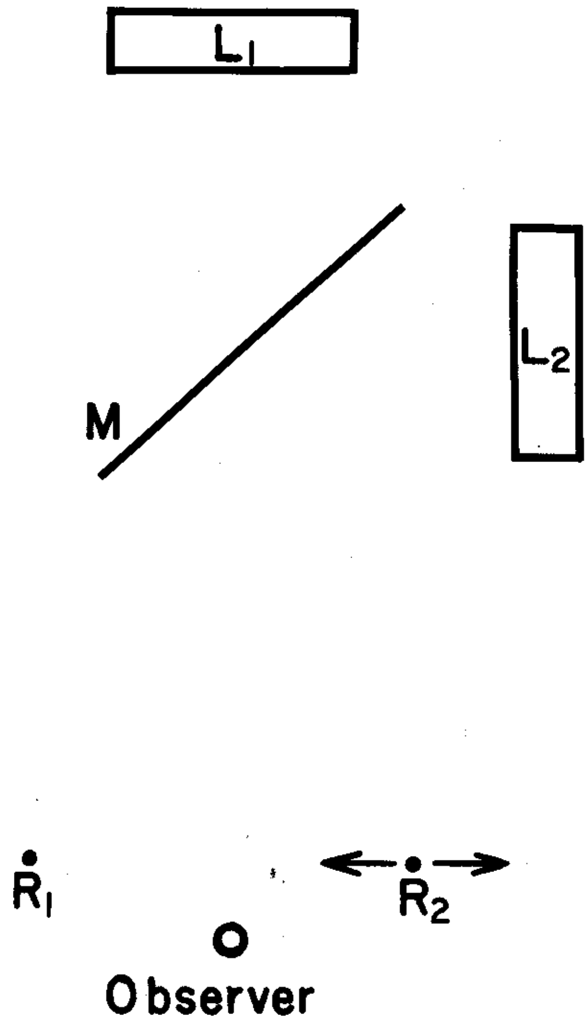

FIGURE 2. A schematic top view drawing illustrating the positions of the light-sources (L_1 and L_2), the mirror (M), and the rods of the hand adjustment apparatus (R_1 and R_2).

faces of L_1 and L_2 in order to produce the Objects A, B, or D of Fig. 1. When viewed in the otherwise dark environment, the positive transparencies appeared to *O* as seven-of-spades playing cards. Object C in Fig. 1c was formed from a 17.8 cm. square of neutral density film fastened on the front surface of L_1 and L_2. As indicated in Fig. 3a, Object C appeared to be interposed in depth between Cards B and D. This was accomplished by cutting away 4% of the upper right area of Object C and 22.4% of the upper right area of Object B and carefully fitting the objects together. Object C appeared to *O* to be a gray square partially covering Playing Card B and partially covered by Playing Card D. Actually, of course, all of the objects (Objects A, B, C, and D) were at the same distance (305 cm.) from *O*. The portions of the front surfaces of the light boxes L_1 and L_2 not used in producing the playing cards or gray square were completely covered by black opaque cardboard. The visual stimuli presented by means of L_1 are illustrated in Figs. 3a and 3b. The presentation shown in Fig. 3b was produced from that of Fig. 3a by carefully covering Card B. The visual stimulus presented by means of L_2 is illustrated in Fig. 3c. It will be observed that Fig. 3b and Fig. 3c are the same as Fig. 3a except that Card B is missing from Fig. 3b and Card D is missing from Fig. 3c. The luminance of Object C and of the white portions of the playing cards was 0.5 and 3.0 ft.-L, respectively, as measured from the position of *O*'s eye.

The viewing position of *O* was enclosed in black cloth and contained a head and chin rest together with a pair of eye-pieces. The right eye-piece had an opening which enabled *O* to see the stimuli through an invisible neutral density filter (19% transmission). The left eye-piece was occluded. Thus, the stimuli were seen by *O* with his right eye only. Only one light-box was turned on at a time with the remainder of the field-of-view completely dark. The position and orientation of the light-boxes were such that regardless of which light-box was turned on the size, brightness, direction, and distance of the particular object (A, B, or C) were the same. A light-adaptation surface (3 ft.-L) located to the left of *O*'s position could be turned on or off by the experimenter (*E*) to control *O*'s light-adaptation.

A device for measuring the perceived depth between the several playing cards was also located at the position of *O*. This device consisted of two vertical metallic rods (15.2 cm. high and 1.3 cm. in diameter) which *O* could grasp, one in each hand. The right rod (R_2 in Fig. 2) was movable laterally, with the left rod (R_1 in Fig. 2) fixed in position. The lateral distance between the inner edges of the rods was adjusted by *O* to be perceptually equal to the perceived *depth* between the designated

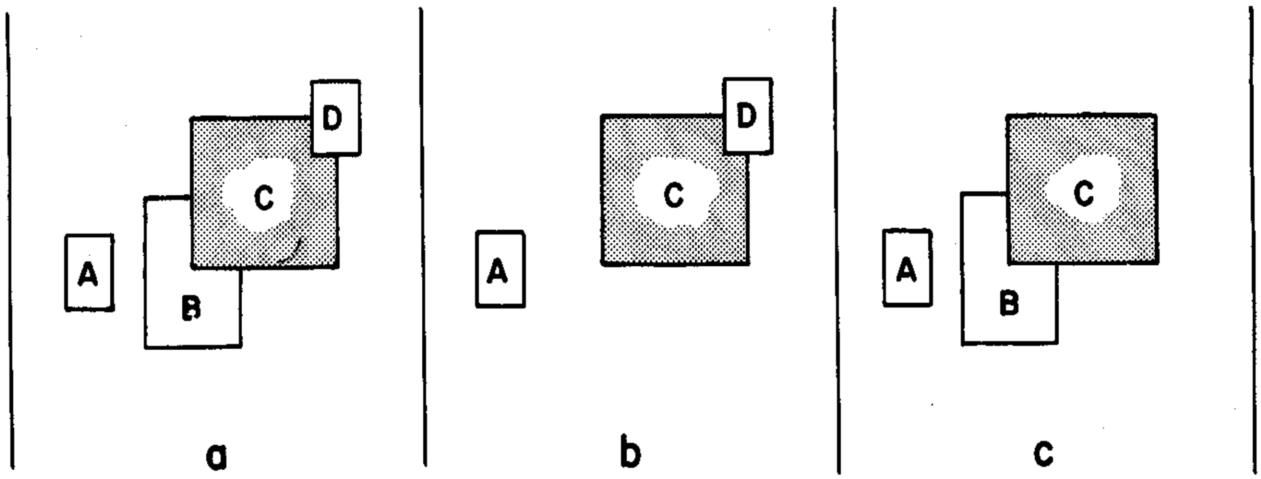

FIGURE 3. A schematic front view drawing illustrating the positions of the normal-sized cards (A or D), the double-sized card (B), and the gray square (C) for the condition in which all three cards were present (Fig. 1a) or in which one card was absent (Fig. 1b or Fig. 1c).

playing cards. The hand adjustment apparatus was invisible to *O* and the adjustment was made kinesthetically. By means of a centimeter-rule attached to the apparatus, *E* could measure the adjusted separation between the rods.

Procedure

The three displays illustrated in Fig. 3 were presented to each of twenty *O*s (17 men and 3 women). Each *O* had a visual acuity in his right eye (corrected if necessary) of at least 20/20. The perceived depth between playing cards which *O* was asked to indicate by means of the hand adjustments (task) and the conditions under which each task was completed were as follows:

Task (1). To indicate the perceived depth between A and D under conditions illustrated in Fig. 3a, i.e., B present.

Task (2). To indicate the perceived depth between A and D under conditions illustrated in Fig. 3b, i.e., B absent.

Task (3). To indicate the perceived depth between A and B under conditions illustrated in Fig. 3c, i.e., D absent.

Task (4). To indicate the perceived depth between A and B under conditions illustrated in Fig. 3a, i.e., D present.

Task (5). To indicate the perceived depth between B and D under conditions illustrated in Fig. 3a.

The order in which these five tasks were completed was systematically varied between *O*s, with each perceived depth being measured three times.

If the size cue between Cards A and B contributed to the perception of the depth position of Card A, the perceived depth position of Card A as judged with respect to Card D should be more distant (farther behind Card D) when Card B was present (Task 1, Fig. 3a) rather than absent (Task 2, Fig. 3b). Therefore, the obtained difference between Tasks (1) and (2) is a measure of the *effect of Card B* on the perceived depth position of Card A. Similarly, if the size cue between Cards A and D contributed to the perception of the depth position of Card A, the perceived depth position of Card A as judged with respect to Card B should be more distant (farther behind Card B) when Card D was absent (Task 3, Fig. 3c) rather than present (Task 4, Fig. 3a). Therefore, the obtained difference between Tasks (4) and (3) is a measure of the *effect of Card D* on the perceived depth position of Card A. According to the adjacency principle, the effect of Card B on the apparent position of Card A should be greater than that of Card D. The purpose of Task (5) was to determine that the interposition cue was effective in modifying the perceived depth between B and D from that which would have normally been expected as a consequence of the size difference between these two objects.

In the instructions to *O*, prior to the experiment, care was taken to be certain that *O* understood that the distance between the playing cards which was to be measured by the hand adjustment was the perceived depth component only. A small pegboard with two pegs was used to illustrate the difference between frontoparallel and depth extents. Following the experiment, *O* was questioned to further determine that the extent which *O* had indicated by means of the hand adjustment was the perceived depth (not the frontoparallel) separation between the playing cards.

Following a set (three) of hand adjustments to indicate the perceived depth between a specified pair of playing cards, *O* turned and faced the light-adaptation surface which was turned on for approximately ten seconds. This procedure of obtaining three measurements of apparent depth followed by a period of light-adaptation was repeated until all five tasks had been completed.

RESULTS

The average results from the hand adjustments are shown in Table 1. The terms d'_{DA} and d'_{BA} indicate the average perceived depth between Playing Cards A and D or between Playing Cards A and B, respectively. A positive value indicates that the left card of the two cards being considered appeared to be behind the right card. A negative value indicated the converse. One potential *O* who failed to perceive Card A as behind Card B in the situation in which Card D was absent (Task 3) was not used in the experiment. A positive response value on Task (3) was considered to be essential to the experiment, since it indicates that the *O* was responsive to the size cue to relative depth. The 38.5 cm. difference in Table 1 represents the effect of Card B upon the perceived depth-position of Card A and the 3.5 cm. difference represents the effect of Card D upon the perceived depth position of Card A. It seems that the size cue between Playing Cards A and B was more effective than the size cue between Playing Cards A and D in determining the apparent position of Playing Card A. The present study supports the validity of applying the adjacency principle to size cues of relative depth.

The average result from the measurements of the perceived depth between Cards B and D is that Card B appeared to be located 20.4 cm. behind Playing Card D.

DISCUSSION

The results from this study demonstrate that *the size cue between Cards A and B was dominant in determining the perceived depth position of Card A. This occurred even when O's task was to judge the depth between Cards A and D.* It is clear that *O* cannot use the size

TABLE 1

THE AVERAGE PERCEIVED DEPTH (d') IN CENTIMETERS BETWEEN PLAYING CARDS AS MEASURED BY THE HAND ADJUSTMENTS

Presence or Absence of B	Perceived Depth Bet. A and D (d'_{DA})	Presence or Absence of D	Perceived Depth Bet. A and B (d'_{BA})
B Present	38.2**	D Absent	30.5**
B Absent	− 0.3	D Present	27.0**
Diff.	38.5**	Diff.	3.5*

* $p < .05$ (*t* test)

** $p < .01$ (*t* test)

cue to relative depth between one object and a displaced object independently of size cues between this object and adjacent objects. However, the results also indicate that while the size cue between Playing Cards A and D was not very effective in determining the perceived position of A, it was not completely ineffective as shown by the statistical significance of the 3.5 cm. difference in Table 1. This is interpreted to mean that both the size cues between Cards A and B and between Cards A and D were significant in determining the perceived position of Card A. However, Card B, the most adjacent object to Card A, was considerably more effective than Card D in this process.

It is clear that the adjacency principle can be successfully applied to the perceived depths between the cards. Nevertheless, it is possible that the effectiveness of a size relation between two objects might be enhanced by the task of judging the depth between them. Suppose, for example, that the task of judging the depth between Cards A and D (task-set) had enhanced the relative effectiveness of the size cue between Cards A and D over that between Cards A and B. In this case, the apparent depth position of A in the visual field would have been closer to *O* when judging the depth between Cards A and D than when judging the depth between Cards A and B.

An illustration of the possible effect of task-set upon cue-enhancement is shown in the top view drawing in Fig. 4. In Fig. 4, the position of *O* is to the left. Card D is indicated as perceived in front of the gray square (C) which is perceived in front of Card B. Thus, Card B is perceived to be a distance d'_{DB} behind Card D. Suppose that the perceived depth of Card A with respect to Card B (d'_{BA}) is as shown. It is clear that the perceived depth between Cards A and D which would be expected is d'_{DB} plus d'_{BA}, i.e., Card A should have appeared at A'_f. Assume, however, that the judgment of the depth between Cards A and D had enhanced the effectiveness of the relative size-cue between Cards A and D. Under these conditions, the apparent position of Card A would have been at A'_n instead of at A'_f. Thus, the difference between A'_f and A'_n is a measure of the in- influence of task-set upon the effectiveness of

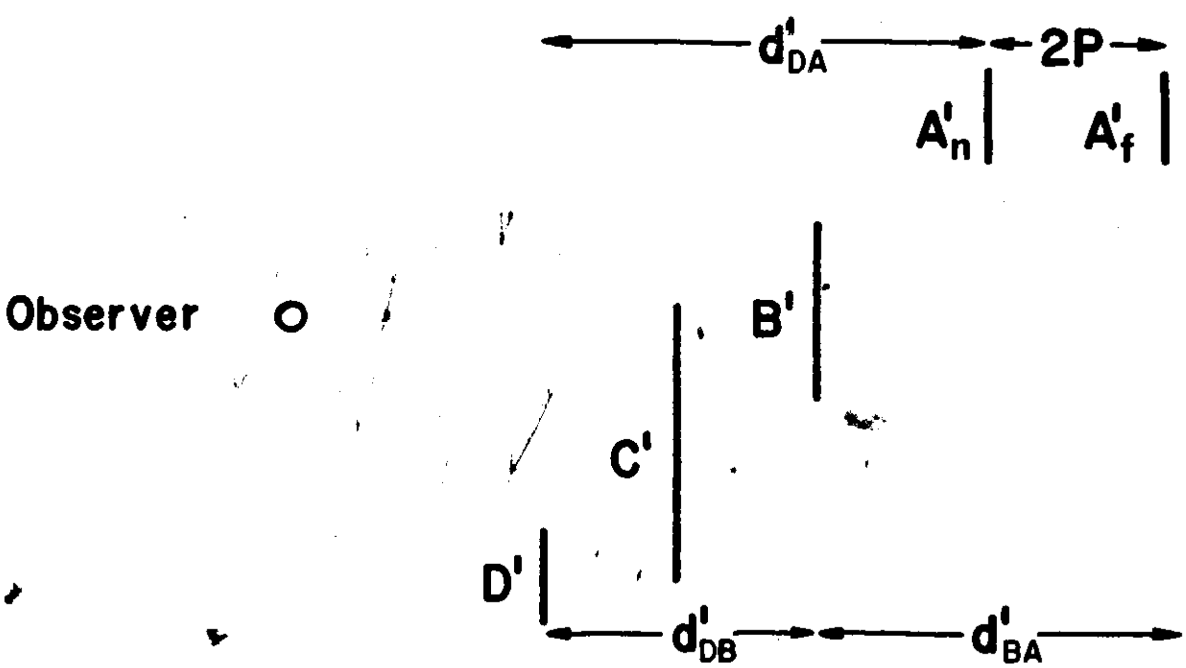

FIGURE 4. A schematic top view drawing illustrating the possible enhancement of the effectiveness of size cues as a function of task-set.

the cue of relative size between the objects being judged. Since two judgments of depth with respect to the relative size cue are involved (d'_{DA} and d'_{BA}), the enhancement effect (T) of task-set is given as

$$T = \frac{d'_{DB} + d'_{BA} - d'_{DA}}{2}$$

The obtained average value of T in the present study is 4.6 cm. which, using a single-tailed test, is significantly different from zero at the .05 level ($t = 1.80$). This suggests that in the present experiment *O* showed some enhancement of the effectiveness of the relative size cue between two objects as a consequence of the task of judging the depth between them. However, compared to the magnitude of the adjacency effect, the set-enhancement effect was minor.

In a previous study (Gogel & Harker, 1955) it had been found that the relative effectiveness of size cues increased with an increase in their lateral separation. It was later found (Gogel, 1956) that this result was attributable to a decrease in the effectiveness of the "equidistance tendency" as a function of the increased lateral separation, not to an increase in the effectiveness of the size cue to relative depth. Thus, the results from the present study and the previous study are compatible.

The "equidistance tendency" (Gogel, 1956) states that there is a tendency for objects to appear equidistant with the strength of this tendency inversely related to the directional separation between the objects. Although most effective when the depth cues between objects are eliminated, the equidistance tendency possibly could have had a significant effect upon the results of the present experiment. In the present study, the addition of Card B or D introduced the equidistance tendency as well as the size cue between that card and Card A. The equidistance effect would have made Card A appear closer in depth to Card B when B was added and closer in depth to Card D when D was added, with the latter effect being less than the former. However, the equidistance tendency could not have resulted in Card A being perceived behind Card B. As given in Table 1, on the average, Card A was perceived to be 38.2 cm. behind Card D with Card B present. This is 17.8 cm. more than the average perceived depth (20.4 cm.) between Card B and D, with the 17.8 cm. difference statistically significant beyond the .01 level ($t = 3.24$). Also, the value of 17.8 cm. is significantly greater ($p < .01$, $t = 2.70$) than the total effect attributed to Card D (3.5 cm. in Table 1). Thus, it is clear that the size cue between Cards A and B was the most significant factor present in determining the apparent depth between Cards A and D. In agreement with the adjacency principle, the present study demonstrates that the size cue between Card A and the more adjacent card was considerably more effective than that between Card A and the displaced card in determining the apparent depth position of Card A.

In a previous discussion of the adjacency principle, it has been pointed out that the term "adjacency" needs clarification (Gogel, 1963). It was noted that adjacency can be either physical, retinal, or perceptual. When objects are positioned at physically different distances from *O*, with effective depth cues present, they may be adjacent on the retina even though both physically and perceptually they are separated in depth. But, it has been demonstrated that depth as well as directional adjacency is important in the adjacency principle (Gogel, 1963) and, therefore, it is unlikely that the adjacency factor can be defined as retinal adjacency. Also, since the adjacency principle applies to the size cue to relative depth, as the present study demonstrates, it is unlikely that the adjacency factor can be defined as physical adjacency. In the present study, Objects A, B, C, and D were all at the same distance from *O*. It is clear, however, that they could have been located at different distances and could have resulted in the same perceived depths if (1) the physical sizes of the objects had been appropriately changed to produce the same visual angles (retinal sizes) and (2) all perceptual cues as to physical distances had been removed. *It seems, therefore, that the term "adjacency" in the adjacency principle is neither a retinal nor a physical adjacency. It is a perceived adjacency!*

The presence of both Cards B and D contributed to the apparent depth position of Card A even though the perceptual effect on Card A of the adjacent card (B) was much greater than that of the displaced card (D). These considerations suggest that a more specific statement of the adjacency principle is as follows: *The perceived size or distance of an object (Object A) in a configuration of objects is determined by whatever size or distance cues are present between Object A and other objects, with the effectiveness of such cues being inversely related to the perceived relative separation of the objects from Object A.*

It is likely that the apparent characteristics of objects other than size and distance (such as brightness) would also be determined by the adjacency principle. It is suggested that the adjacency principle can be applied to a variety of cue systems under a variety of stimulus conditions.

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