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Perception of Partly Occluded Objects in Infancy

PHILIP J. KELLMAN AND ELIZABETH S. SPELKE

University of Pennsylvania

Four-month-old infants sometimes can perceive the unity of a partly hidden object. In each of a series of experiments, infants were habituated to one object whose top and bottom were visible but whose center was occluded by a nearer object. They were then tested with a fully visible continuous object and with two fully visible object pieces with a gap where the occluder had been. Patterns of dishabituation suggested that infants perceive the boundaries of a partly hidden object by analyzing the movements of its surfaces: infants perceived a connected object when its ends moved in a common translation behind the occluder. Infants do not appear to perceive a connected object by analyzing the colors and forms of surfaces: they did not perceive a connected object when its visible parts were stationary, its color was homogeneous, its edges were aligned, and its shape was simple and regular. These findings do not support the thesis, from gestalt psychology, that object perception first arises as a consequence of a tendency to perceive the simplest, most regular configuration, or the Piagetian thesis that object perception depends on the prior coordination of action. Perception of objects may depend on an inherent conception of what an object is.

The objects that surround a perceiver, at any point of observation, are only partly in view. Every object's back is occluded by its front, and even its front may be partly concealed by other things. Human adults nevertheless perceive a world of complete and solid objects, not visible fragments. We perceive objects to continue, in certain definite ways, in the places where they are hidden. The present experiments were undertaken to investigate the origins of perception of partly occluded objects, and of the capacities that make object perception possible.

As adults, we perceive the shapes of partly hidden objects in several ways. We sometimes perceive objects by analyzing certain of the config-

Reprint requests should be sent to Philip J. Kellman who is now at the Department of Psychology, Swarthmore College, Swarthmore, PA 19081. Portions of this research were submitted by P.J.K. to the University of Pennsylvania in partial fulfillment of the degree of Doctor of Philosophy. Portions of this research were presented at the 1979 and 1981 meetings of the Society for Research in Child Development. This research was supported by PHS research Grant HD-13248 to E.S.S. and by a PHS predoctoral fellowship to P.J.K. (MH-07814). Many people have helped us with this work over the years. We especially thank Renée Baillargeon, Wendy Smith Born, Rochel Gelman, Henry Gleitman, Lila Gleitman, Claes von Hofsten, Julian Hochberg, Dorothea Jameson, Jacob Nachmias, and Hilary Schmidt.

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urational properties of edges and surfaces. The importance of configurational properties was first emphasized by the gestalt psychologists. Their principles of organization, e.g., the principles of proximity, similarity, good continuation, and good form, have been shown to affect the organization of two-dimensional forms into groups (Wertheimer, 1923/1958; Koffka, 1935; see also Kubovy & Pomerantz, 1981, for a review of recent research). It has often been suggested that the same principles underlie the organization of three-dimensional scenes into objects (Koffka, 1935; Michotte, Thinès, & Crabbé, 1964; Pomerantz, 1981). In the scene depicted in Fig. 1, for example, the principles of good form, good continuation, and similarity dictate that the harpsichord continues in a definite way behind the musicians. While the gestalt principles have been difficult to formulate precisely (see Hochberg, 1974), they continue to provide a framework for the study of perceptual organization (see Kubovy & Pomerantz, 1981; Beck, 1982).

Adults also perceive partly hidden objects in other ways. We sometimes perceive an object by identifying the kind of object that it is and by bringing to bear knowledge about objects of that kind. Knowledge about stringed instruments, for example, allows us to apprehend the complete shape of the cello in Fig. 1 even though much of it is hidden. Sometimes we perceive objects, moreover, by drawing on knowledge of more general properties of the physical world. We may perceive two surfaces as connected or separate because of knowledge of gravity and of the conditions under which an object requires support. Such knowledge may indicate that the back of the central chair in Fig. 1 must be attached to its seat, behind the occupant's jacket, and that the jacket and chair need not be connected. Finally, sometimes we perceive objects by analyzing the movements of surfaces. When two surfaces move together in a rigid relationship behind an occluding object, we tend to perceive them as connected. This phenomenon may again reflect our tendency to organize the perceptual world into the simplest configurations (Wertheimer, 1923). Alternatively, it may reflect our knowledge that objects do not tend to act on each other at a distance; thus, if they move together, they are probably connected.

Theories of object perception offer different accounts of the origins of the ability to perceive partly hidden objects. According to gestalt theory, the principles of organization all derive from intrinsic forces within the nervous system, independently of what we know and learn, and our experience of objects arises automatically as a consequence of these forces (Koffka, 1935; Köhler, 1947). While the particular gestalt neurophysiological hypotheses have largely been abandoned (Hochberg, 1974), the idea of an innate basis for object perception, embodying in some way the tendency to perceive the simplest, most regular configurations, persists

FIG. 1. "The Concert," by Johannes Vermeer. Boston, Isabella Stewart Gardner Museum. Reproduced with permission.

in recent theorizing (Johansson, 1970; Shepard, 1981). On this view, infants should perceive the complete shapes of partly hidden objects as soon as they can detect certain configural relationships in visual scenes, such as the alignment of visible surfaces and the similarity of their colors and textures.

In contrast to the thesis of gestalt psychologists and their descendants is the thesis that perception of objects depends on a system of constructions that take place over the course of infancy and early childhood on the basis of more primitive abilities to sense and to act. One such theory, that of Piaget, has many contemporary adherents. According to Piaget, perception of objects depends on the gradual structuring of actions that takes place over the first 2 years of life (Piaget, 1954; Harris, 1983). As a child acts on objects in different ways, these actions become coordinated and action structures arise. The principles governing these structures come to underlie our experience and our conceptions of objects and the physical world. According to this view, inexperienced infants cannot perceive partly hidden objects in visual scenes, but only a "tableau" of visible surfaces. In this respect, Piaget's theory resembles that of empiricist philosophers (e.g., Berkeley, 1709; Mill, 1865) and their descendants in psychology (e.g., Helmholtz, 1885/1925; Hochberg, 1981; Rock, 1977).

A third view may be contrasted with these. The ability to perceive objects may emerge in infancy, without learning, by virtue of an inherent general conception of the physical world (Spelke, 1983). Infants, like adults, may conceive of the world as composed of things that are spatially connected, that move independently of each other, and that persist over their free movements. With this conception, infants would be able to perceive partly hidden objects by analyzing the spatial arrangements and the movements of surfaces. In particular, infants who are presented with two surfaces partly hidden by the same occluder should perceive the surfaces as parts of a single object if the surfaces move rigidly together. The infants might not perceive a unitary object, however, by using other sources of information that are effective for adults.

Existing research does not permit a choice among these theories. Evidence from studies of adults has been claimed to show that perception of partly occluded objects is independent of experience, since an adult's perception of a partly hidden object is sometimes not affected by what she or he learns about the object (Michotte et al, 1964; see Fig. 2). Such demonstrations do not, however, exclude the possibility that rules of object perception originally develop through experience. Research on infants' perception of partly hidden objects provides a more direct approach to this question. Few such studies have been conducted, however,

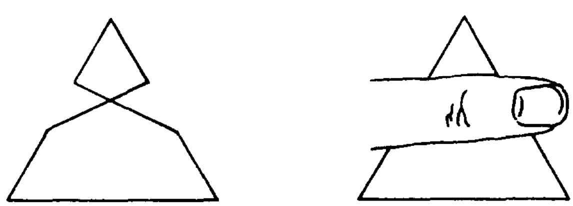

FIG. 2. Type of display used by Michotte, Thinès, and Crabbé (1964). (After repeated covering and uncovering of the middle of such a display, subjects reported that it "looked" like a simple triangle when covered, even though they knew its actual shape.)

and their results do not agree. Bower (1967) conditioned 1-month-old infants to suck in the presence of a partly covered wire triangle similar to that studied by Michotte et al. (1964). In a subsequent generalization test, infants were reported to respond more to a complete triangle than to displays in which the contours of the triangle were interrupted in the region that had been occluded. It appeared that infants perceived the object in accordance with one or more of the principles of good form, closure, good continuation, and similarity. However, infants were reported not to perceive the complete shapes of partly hidden objects in research by Piaget (1954). Piaget described many experiments in which a familiar, desired object (e.g., a toy or bottle) is presented so that it is partly hidden and the infant is allowed to reach for it. He reported that until about 6 months of age, infants do not reach for, or otherwise appear to identify, the object under these circumstances.

Given the differences between the methods and the displays used in these different studies, it is difficult to compare them or to evaluate their findings. What is needed is a systematic investigation of infants' perception of partly occluded objects under a variety of stimulus conditions. Our own research was undertaken for this purpose. We have conducted a series of experiments on 4-month-old infants' perception of the unity of a three-dimensional object whose ends are visible but whose center is hidden. In different experiments, infants were presented with objects whose visible surfaces were united by various kinetic and configurational properties. The experiments investigated whether, and under what conditions, infants would perceive these surfaces as connected behind the occluder. Such experiments, we hoped, would help to reveal whether the earliest perception of objects depends on an inherent tendency toward simplicity, on the structuring of action, on an unlearned conception of what an object is, or on some combination of these factors.

The experiments used a habituation procedure. When infants are shown a visual display repeatedly, they usually come to look at it less and less. If a novel display is then introduced, their looking time usually increases. The amount of increase often depends on the similarity of the test display to the original display: infants look longest at new displays that adults judge to be most different from the original display. These changes in attention have been observed in experiments using a wide variety of visual patterns (for reviews, see Bornstein, 1982; Cohen & Gelber, 1975; Tighe & Leaton, 1976). They are sufficiently reliable that they now serve as a principal measure of perceived similarity in studies of infancy.

In the present experiments, infants were habituated to an object whose center was occluded by a block, and then they were shown two test displays with no block present. In one display, the two ends of the object were connected where the block had been. In the other display, the two ends were separated by a gap. If the infants perceived the original, partly hidden object as connected behind the occluder, then they were expected to look longer at the object with the gap. If the infants perceived two objects that ended where the occluder began, then they were expected to look longer at the connected object.

EXPERIMENT 1

Our first study investigated whether infants would perceive the unity of a partly hidden object in accordance with the principles of good continuation, similarity, and common fate. Infants were presented with a rod whose center was hidden by a block and whose visible surfaces were aligned, had the same color and texture, and underwent a common, rigid, translatory movement behind the block. We asked if infants perceived the ends of the rod as connected behind the block.

Each infant was observed in one of two conditions. Infants in the experimental condition were habituated to the moving, partly hidden rod and then were tested with moving complete and broken rods. To assess baseline preferences between these test displays, infants in the baseline condition were shown the same test displays after habituation to a rod and block configuration in which the surfaces of the rod were not aligned and did not move together: a configuration that does not give rise to perception of a unitary object for adults. If infants perceive the unity of partly hidden objects by analyzing the movements or the configurations of surfaces, then those in the experimental condition should look relatively longer at the broken rod than infants in the baseline condition.

METHOD

Subjects

Thirty-two infants participated in the experiment. All resided in the Philadelphia area, and all were born of full-term pregnancies. The infants ranged in age from 3 months, 15 days, to 4 months, 19 days (mean: 3 months, 29 days). An additional 11 infants failed to complete the experiment because of fussiness (8 infants), equipment failure (2 infants), or experimenter error (1 infant). Names of subjects were obtained from birth announcements in local newspapers. Parents were recruited by letter and telephone and were compensated for their participation.

Displays and Apparatus

There were two habituation displays in the experiment. One consisted of a black wooden dowel rod moving laterally back and forth behind a tan, wooden block[1] (see Fig. 3). The rod was 53 cm long and 1.3 cm in diameter, oriented at a 20° angle from the vertical. The block was 25 cm wide, 13 cm high, and 3.8 cm thick, and was oriented horizontally. The

[1] For half of the subjects, the display actually consisted of two separate, aligned rod pieces, with the gap between them occluded, moving behind the block.

rod and block were presented in front of a white pegboard surface, 76 cm high and 86 cm wide, to which they were attached. The rod was suspended 10 cm in front of this surface, and the block was suspended 5 cm in front of the rod. At the infant's viewing distance (about 95 cm), each visible surface of the rod subtended visual angles of 12.8° (length) and .75° (width), and the block subtended angles of 15.5° (horizontally) and 7.9° (vertically). The rod underwent a lateral translation, back and forth, while the block and the background remained stationary. The rod traversed 15 cm from side to side at a real velocity of 7.5 cm/sec (angular velocity: 4.5°/sec), pausing .5 sec at each end. The rod never moved far enough for its center to become visible.

The second habituation display consisted of the same visible rod surfaces moving in a different pattern (see Fig. 3). The top of the rod moved back and forth behind the block, as in the experimental condition, while the bottom of the rod remained stationary. Again, the block and the background were stationary.

In addition to the two habituation displays, there were two test displays: a moving complete rod and a moving broken rod presented without the block (see Fig. 3). The complete rod was the same as in the first habituation display. The broken rod display consisted of

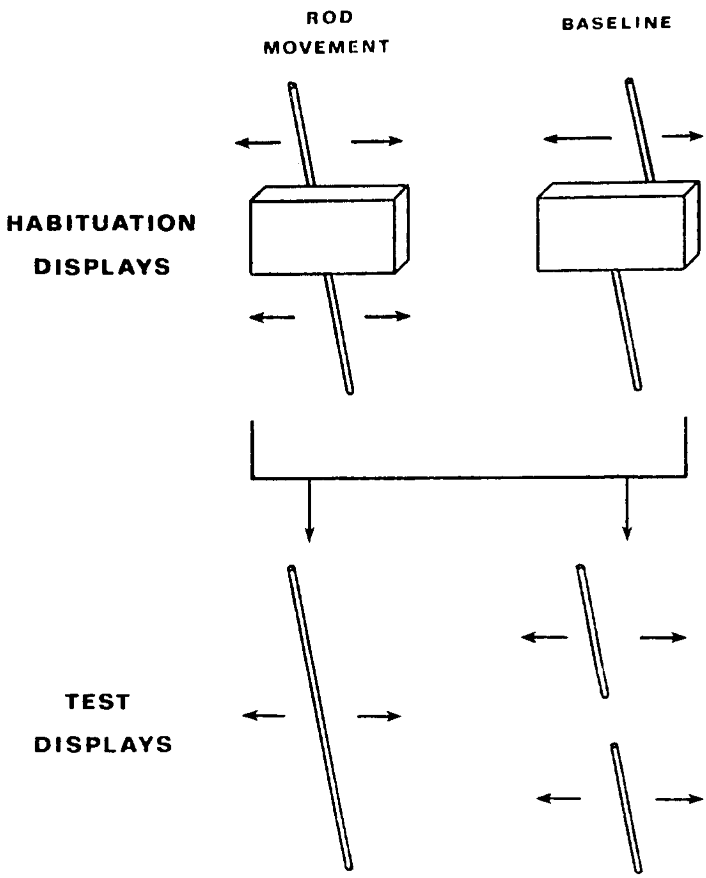

FIG. 3. Displays and design in Experiment 1.

two 21.5-cm pieces with a 10-cm gap between them. Both rod figures moved in the same unitary translation as did the rod figure in the first habituation display.

Each display was presented at the back of a large display box with a plain white floor and tan sides. It was illuminated from overhead by one 100-W and one 60-W sunlight bulb through a translucent diffusing cover. Stimulus presentation was automatically controlled by a motor-driven curtain which opened and closed between the subject and the display box.

Design

Infants were randomly assigned to the experimental or the baseline condition, with 16 subjects in each. The conditions differed only with respect to the habituation display: Infants in the experimental condition were habituated to the display in which the visible rod parts were aligned and moved together. Infants in the baseline condition were habituated to the display in which only the top visible rod part moved while the bottom part was stationary.[2] After habituation, infants in both conditions were tested with the complete and broken rods undergoing the unitary movement (see Fig. 3). These test displays were presented in alternation for three trials each. Half of the subjects in each group saw the broken rod display first.

Procedure

At the beginning of the study, a baby was placed in a standard infant seat centered in front of the display box. The curtain opened to reveal a rod and block display, and it remained open until the infant looked away from the display for two continuous sec, after looking at the display continuously for at least .5 sec. The curtain reopened automatically after an interval of 3 sec. Closing and opening the curtain each took an additional 1.5 sec.

The infant saw a single display repeatedly until a criterion of habituation was met. This criterion was a 50% decline in looking time, calculated by summing looking times on the first three trials, dividing this total in half, and summing sets of subsequent trials until three consecutive trials were obtained whose total looking time was less than or equal to this value. If looking time on the first three trials was less than 12 sec, the criterion was based on the first three consecutive trials for which total looking exceeded 12 sec. After the criterion was met, the block was removed, and infants saw the two test displays three times each on alternating trials. The test displays were changed during the 3-sec period that the curtain was closed. The test trials were otherwise identical to the habituation trials.

Looking time was recorded by two observers who viewed the infants through holes in the pegboard background. The observers used push buttons connected to an event recorder. Interobserver agreement (proportion of total time both observers were registering a look or nonlook) ranged from .77 to .98 and averaged .89. Observers were unable to see the display objects and were not told which display was being presented. One observer was designated as the primary observer: His or her responses were used to calculate when a trial should end and when the criterion of habituation was met. The primary observer also decided whether to suspend or terminate the experiment if an infant became fussy. A third assistant calculated the habituation criterion by reading looking time durations from a clock, and a fourth person changed the displays at the appropriate times.

[2] It might be argued that this occlusion display is not appropriate for a baseline condition. Infants habituated to this display might perceive two clearly separate rods and generalize more to the broken rod display, since the top moved independently from the bottom, and the rod parts were not aligned. We have found, however, the same patterns of preference in this baseline condition as in other conditions where such an argument does not apply. See Experiment 5.

If an infant became fretful during the first three trials, the experiment was stopped for several minutes and was begun anew if possible. If the infant became fretful later in the habituation series, the experiment was interrupted and resumed if possible, with at least three new trials required to meet the habituation criterion. If the infant became fretful during the test series, the experiment was terminated and the subject was replaced. No subject had more than one break during the habituation period.

Dependent Measures and Analyses

The principal measure was the amount of increase in looking, or recovery from habituation, to each test display the first time that it was presented. This was calculated by subtracting the looking time on the last habituation trial from the looking time on each of the first two test trials. Negative scores on a test trial are suggestive of continued habituation, whereas positive scores are suggestive of dishabituation.[3] The recovery scores obtained for each infant were subjected to a 2 (habituation group) $\times$ 2 (test display) analysis of variance (ANOVA).

Infants' looking patterns during the habituation and test trials were subjected to further analyses. t Tests compared the patterns of habituation of infants in the two groups on four measures: duration of looking on the first habituation trial, number of trials to habituation, total looking time during the habituation period, and mean looking time per habituation trial. Moreover, looking times on the test trials were subjected to a 2 (habituation group) $\times$ 2 (test display) $\times$ 3 (trial block) ANOVA. Unlike the recovery analysis, this analysis was based on actual looking times during all six trials.[4]

Results

Looking times during the habituation and test periods are shown in Fig. 4. Infants in the rod movement group did not dishabituate to the complete rod test display and dishabituated dramatically to the broken rod test display. Infants in the control group looked equally at the two test displays, dishabituating somewhat to each.

The analyses confirmed these patterns. The two groups did not differ on any of the habituation measures, all t's(30) < 1.19, n.s. Analysis of the recovery scores (see Table 1) showed a main effect of test display, $F(1,30) = 9.58$, $p < .005$ and a reliable interaction of group and test display, $F(1,30) = 9.22$, $p < .005$. Individual comparisons showed that recovery to the broken rod was reliably greater in the rod movement group than in the control group, $t(30) = 2.20$, $p < .025$, and recovery to the complete rod was less in the rod movement group than in the control group, $t(30) = 1.70$, $p < .05$ (one-tailed).

[3] Because we used a criterion of habituation, rather than a fixed habituation period, a positive recovery score could reflect regression to the mean rather than true dishabituation. For this reason, comparisons between experimental and control groups were always used to draw conclusions about dishabituation to the test displays.

[4] Looking patterns during the test trials were also analyzed by converting each pair of scores within a trial block into a preference measure. Each presentation of the complete and broken test displays was considered as a single trial, looking time to the two displays was summed, and the proportion of this total time devoted to the broken test display was calculated. In virtually every case, the preference analyses showed the same (usually stronger) effects as the looking time and recovery measures.

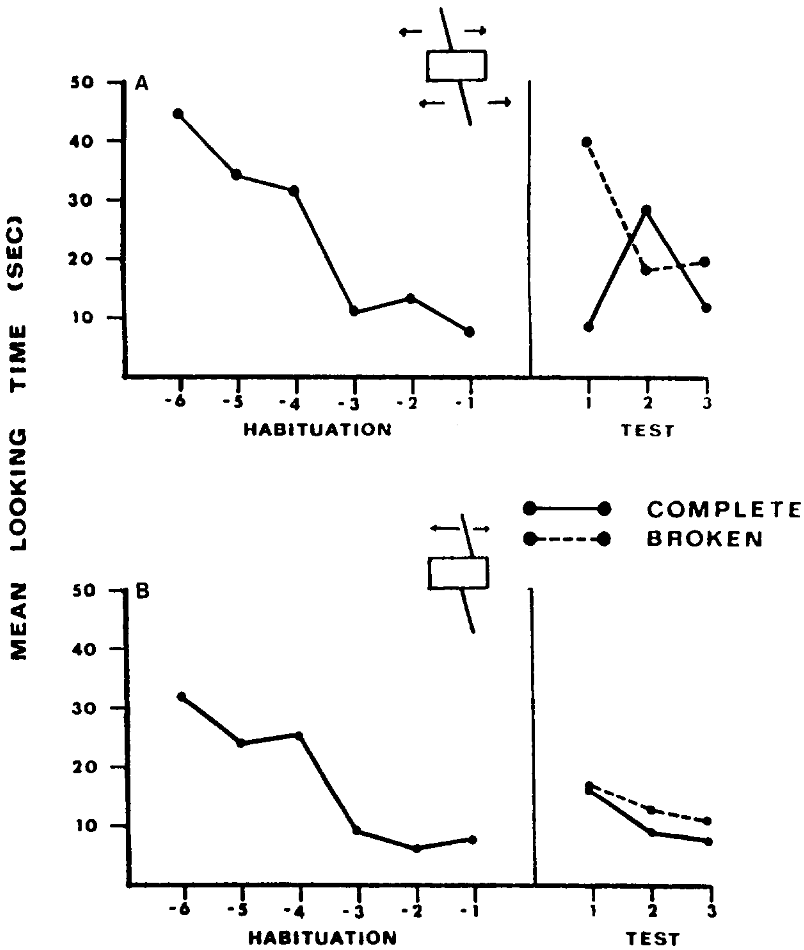

FIG. 4. Looking times in Experiment 1 by infants in (A) the rod movement group, and (B) the baseline group.

Analysis of test trial looking times yielded several reliable effects. There was a main effect of test stimulus, $F(1,30) = 7.44, p < .025$. There were three interactions: a marginal group $\times$ test display interaction, $F(1,30) = 3.21, p < .10$, a test display trial interaction, $F(2,60) = 5.61$, $p < .01$, and a group $\times$ test display $\times$ trial interaction, $F(2,60) = 7.37$, $p < .005$. Individual comparisons by trial suggested that all of these effects are due primarily to the longer looking by the rod movement group to the broken rod on the first pair of test trials, $t(15) = 3.32, p < .005$. The rod movement group showed no reliable difference in looking time on the second pair of trials, $t(15) = -1.31$, n.s., and showed a marginally significant tendency to look longer at the broken rod on the third pair of

TABLE 1
Recovery Scores (in seconds) in Experiment 1

Habituation group	Test display: Complete rod	Test display: Broken rod
Rod movement	.6	32.2
Baseline	8.2	7.9

test trials, $t(15) = 1.74$, $p < .10$ (one-tailed). There were no significant preferences between the test displays by infants in the control group on any pair of test trials, all t's$(15) < 1.52$, n.s.

Discussion

After infants were habituated to a rod that moved as a unit behind a stationary block, they looked longer at a fully visible broken rod than at a fully visible complete rod. This difference does not reflect an intrinsic preference for the broken rod, since infants in the baseline condition showed no such preference. It appears that the infants in the experimental condition treated the complete rod as a familiar object and the broken rod as a novel object. The experiment provides evidence that the infants perceived the visible parts of the original partly hidden object as connected behind the occluder. They did not perceive the partly hidden object to end at the place where its occluder began.

The experiment indicates that infants perceive the unity of a partly hidden object by analyzing the movements of its visible surfaces, the configuration of those surfaces, or both. Infants perceive in accordance with one or more of the gestalt principles of common fate, similarity, and good continuation. In the next experiments, we attempted to separate these factors to assess their independent effects on infants' perception. Experiment 2 investigated infants' perception of the unity of a partly hidden stationary rod.

EXPERIMENT 2

In this experiment, we asked whether infants would perceive the visible ends of a stationary, partly occluded rod as connected behind a block. An adult should perceive these ends as connected since their edges were aligned, their colors and textures were the same, and they could be joined to form an object of a relatively simple shape.

The experiment consisted of three conditions. The infants in the experimental condition were habituated to the stationary rod behind the block. The infants in one control condition were habituated to the same complete rod, presented fully in view in front of the block. The infants in a second control condition were habituated to a broken rod in front of a block. After habituation, all the infants were presented with stationary complete and broken rods on a series of test trials. If infants perceive a stationary, partly hidden rod as connected behind its occluder, then the infants in the experimental condition should dishabituate only to the broken rod, as should the infants in the first control condition. If, in contrast, infants perceive a stationary, partly hidden object as ending where its occluder begins, then the infants in the experimental condition should dishabituate only to the complete rod, as should the infants in the second control condition.

Method

The method of Experiment 2 was the same as that of Experiment 1, except as noted below.

Subjects

Participants were 48 infants aged 3 months, 15 days, to 4 months, 18 days (mean age: 4 months, 4 days). An additional 22 infants did not complete the experiment, due to fussiness (15 infants), equipment failure (5 infants), or experimenter error (2 infants).

Displays

The habituation display in the occlusion condition was identical to that of Experiment 1, except that the rod was stationary, centered behind the block (see Fig. 5). Two control groups viewed habituation displays consisting of rod figures in front of the wooden block. In one, the complete dowel rod was placed 5 cm in front of the block. In the other, a broken rod, consisting of two 21.5-cm long pieces with a 10-cm gap between them, was placed 5 cm in front of the block. The complete and broken rods occupied the same position as the rod in the occlusion display, suspended 10 cm in front of the background surface. In its position behind the rod displays, the block subtended visual angles of 14° (width) and 7.4° (height). Finally, there were two test displays consisting of rod figures with no block present. The complete or the broken rod was positioned as in the rod and block displays.

Design and Procedure

Infants were randomly assigned to three habituation conditions, 16 subjects per condition. The conditions differed only with respect to the habituation display: One group of infants was habituated to the partly occluded rod, one to the complete rod in front of the block, and one to the broken rod in front of the block. After habituation, infants in all three groups were shown the broken and complete rods with no block present (see Fig. 5). These test displays were presented in alternation for three trials each, and half of the subjects in each group saw the broken rod first. The minimum look required to begin a trial was 1 sec in this study.[5] Interobserver agreement ranged from .77 to .98 and averaged .89.

Results

Mean looking times during the last six habituation trials and the six test trials are depicted in Fig. 6. The peak in looking time on the fourth

[5] This was actually the first study conducted; the .5-sec minimum look used in all of the other studies was adopted afterward, since apparently genuine looks at the displays sometimes lasted less than 1 sec.

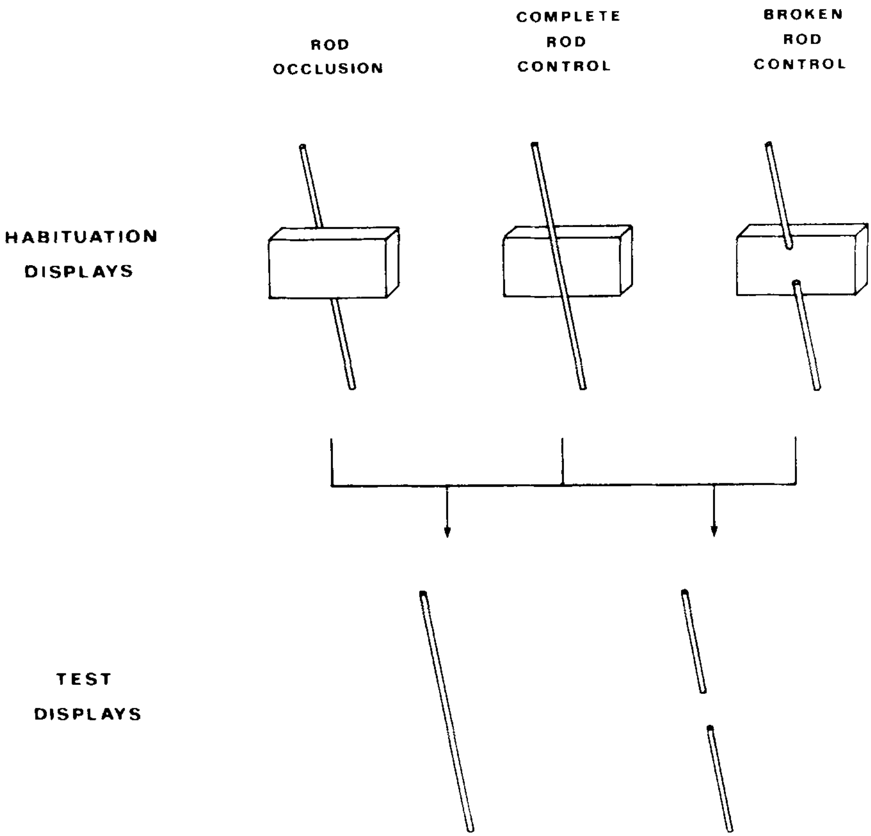

FIG. 5. Displays and design in Experiment 2.

trial before habituation is probably an artifact of our habituation criterion (see Cohen, 1976, p. 230). Infants in the three groups showed a similar decline in looking during the habituation trials, but their looking patterns differed in the test. Infants in the control groups looked longer at the rod display to which they had not been habituated: Those in the complete rod group showed recovery to the broken rod and little or no recovery to the complete rod; those in the broken rod group showed the reverse pattern. In contrast, infants in the rod occlusion group looked equally to the two test displays and showed some increase in looking to each of them.

These patterns were substantiated by the analyses. There were no reliable differences among the groups on any habituation measure, all F's$(2,45) < 1.83$, n.s. The analysis of recovery scores revealed a group $\times$ test display interaction, $F(2,45) = 4.63$, $p < .025$, and no other significant effects (see Table 2). Comparisons between the habituation groups revealed that the degree of recovery shown by the occlusion group

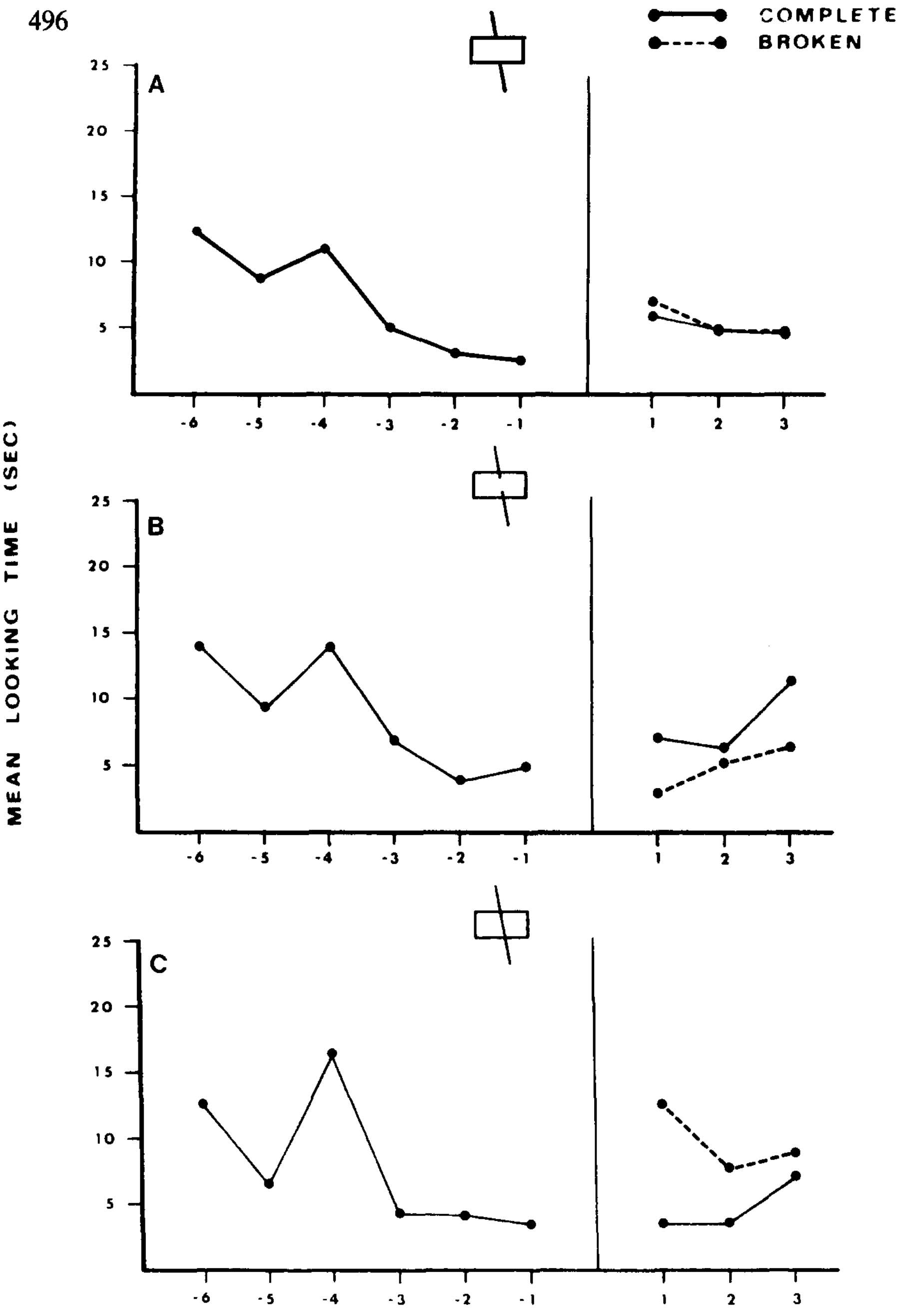

FIG. 6. Looking times in Experiment 1 by infants in (A) the rod occlusion group, (B) the broken rod habituation group, and (C) the complete rod habituation group. (Habituation trials are plotted backward from the trial on which the criterion of habituation was met.)

TABLE 2
Recovery Scores (in seconds) in Experiment 2

	Test display	
Habituation group	Complete rod	Broken rod
Rod occlusion	3.5	4.6
Complete rod control	−.1	8.9
Broken rod control	2.1	−2.0

best approximated looking to the novel displays by infants in the control groups. The infants in the occlusion group increased their looking to the broken rod more than infants in the broken rod control group, $t(30) = 2.59$, $p < .01$, and not significantly less than infants in the complete rod control group, $t(30) < 1$. Similarly, infants in the occlusion group increased their looking to the complete rod more than did infants in the complete rod control group, $t(30) = 1.90$, $p < .05$ (one-tailed), and no less than did infants in the broken rod control group, $t(30) < 1$.

Analysis of looking time on the six test trials revealed only one significant effect: an interaction of habituation group × test display, $F(2,45) = 7.03$, $p < .01$. Individual comparisons for the occlusion group showed no difference in looking times to the two test displays, $t(15) < 1$. The equal looking by infants in the occlusion group evidently was not produced by two subgroups of babies with opposite looking preferences. Inspection of the distributions of looking scores in the three groups suggested no such differences, nor did tests for differences in variances (Keppel, 1973, p. 80) between the occlusion group and each of the other groups, both F's$(1,30) < 1$.

Discussion

Infants who were habituated to a partly hidden rod looked equally afterward at a complete rod and a rod with a gap where the occluder had been. The absence of a looking preference cannot be attributed to floor or ceiling effects, nor to a failure to discriminate the complete and broken test rods, since the infants in the control groups, who exhibited comparable looking times, showed appropriate patterns of dishabituation. Rather, the infants in this experiment appeared to treat both the complete and the broken rods as novel: They dishabituated to both objects as much as the infants in the control groups dishabituated to one of these displays after habituating to the other.

From this experiment, it appears that infants who view a partly hidden rod do not perceive a complete rod continuing behind the occluder, even when the visible parts of this object are of the same shape and color and are aligned. When the rod is not presented in motion, it is not perceived as a unitary object.

The experiment provided evidence that the infants did not, as a group, perceive either a complete rod or two rod fragments. Moreover, the infants did not divide into two subgroups of infants, one of which perceived a complete rod and one of which perceived a broken rod during the habituation period. The experiment does not indicate, however, what the infants *did* see. There appear to be three possibilities. First, the infants might have perceived nothing at all behind the occluding block. When infants are presented with a configuration of stationary objects, perhaps they only attend to the nearest object in that configuration, in this case the block. The infants might have dishabituated equally to the complete and broken test rods because they, unlike the infants in the control groups and in Experiment 1, were seeing rod displays for the first time during the test. Second, the infants might have perceived some definite partly hidden object in the original occlusion display, but not an object that was either a complete or a broken rod. In that case, dishabituation to both the complete and broken rods would occur because neither of these displays corresponded to any object originally perceived. Third, the infants might have perceived the visible ends of the rod but they might have had no definite perception of the parts of the rod that were hidden—just as we usually have no definite perception of the contents of a closed box or an adjacent room. They might have dishabituated equally to the complete and broken rods because both were configurations that *could* have been present in the original display, yet neither was definitely *perceived* to have been present. Experiment 3 was undertaken to investigate these possibilities and to improve our understanding of what infants perceive when they are presented with a partly hidden object.

EXPERIMENT 3

Infants in one condition of this experiment were habituated to a partly occluded rod. Then they were tested with a complete rod display and with a display containing two rod pieces, separated by a gap larger than the area that had been hidden. Infants in a second condition were presented with these test displays after habituating to the rod pieces with the large gap, fully in view above and below the block, and farther away. If infants perceive only the nearest object in a stationary configuration, then infants in both groups should dishabituate equally to the two test displays, both of which were now being seen for the first time. If infants in the occluded rod condition perceived some definite figure that was neither a complete nor a broken rod, they should again dishabituate equally to the two test displays. Finally, if infants perceive the visible rod parts in the occlusion display, but have no definite impression about the

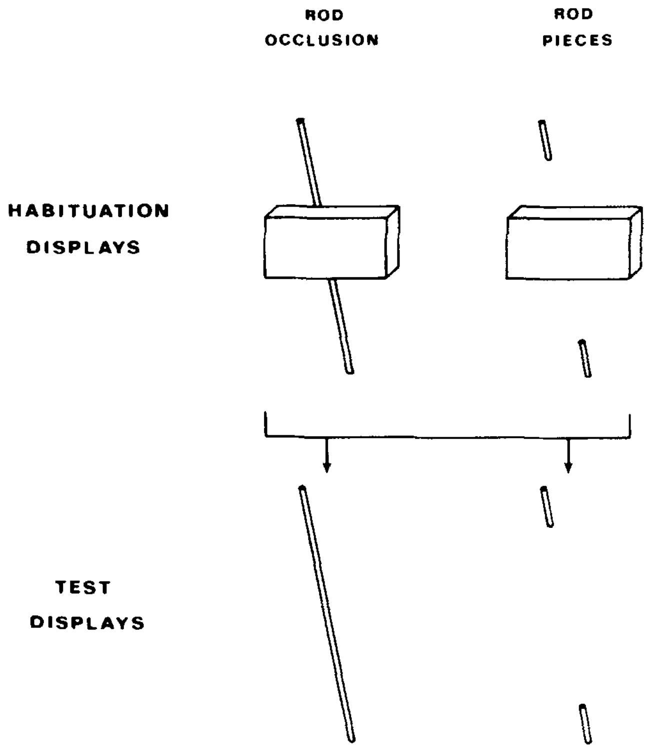

FIG. 7. Displays and design in Experiment 3.

rod boundaries in the occluded area, the infants in each group should dishabituate more to the display that differed from the original rod figure with respect to its visible areas. For in that case, infants should detect a change in the visible surfaces of the rod figure, even if they are neutral about its boundaries in the occluded area.

Method

The method of Experiment 3 was the same as that of Experiment 2, except as noted below.

Subjects

Participants were 32 infants aged 3 months, 15 days, to 4 months, 22 days (mean age: 4 months, 0 days). An additional 9 infants began the experiment but did not complete it, 7 because of fussiness, 1 because of equipment failure, and 1 because of experimenter error.

Displays

One of the habituation displays was identical to that of the occlusion group of Experiment 2: a complete rod standing behind a block. The other display consisted of two 8-cm black rod pieces, placed so as to occupy the same positions as the top and bottom of the standard rod. These pieces stood behind the same block, fully in view. The two test displays were the complete rod and the 8-cm rod pieces (Fig. 7).

Design and Procedure

One group of 16 infants was habituated to a partly occluded rod display. A second group of 16 infants was habituated to the rod pieces with the block nearer and between them. Both groups were tested with the complete rod and the rod pieces (see Fig. 7).

Interobserver agreement in this experiment ranged from .75 to .96 and averaged .86.

Results

Figure 8 depicts the mean looking times on the last six habituation trials and on the six test trials. Infants in the two groups showed a similar decline in looking time over the course of the habituation trials. In the test, those habituated to the rod pieces appeared to dishabituate more to

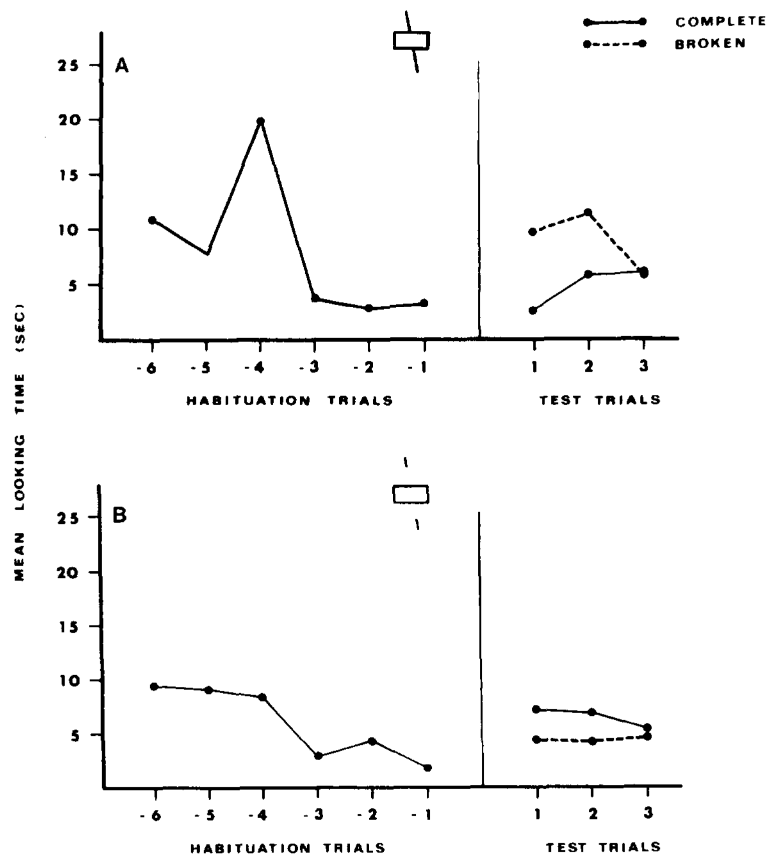

FIG. 8. Looking times in Experiment 3 by infants in (a) the rod occlusion group, and (b) the rod pieces group.

TABLE 3
Recovery Scores (in seconds) in Experiment 3

	Test display	
Habituation group	Complete rod	Rod pieces
Rod occlusion	−.5	6.7
Rod pieces	5.2	2.6

the complete rod, whereas those habituated to the occluded complete rod appeared to dishabituate more to the rod pieces.

The analyses substantiated these findings. Infants in the two habituation groups did not differ on any of the four measures of looking during the habituation sequence, all t's $< .86$, but they differed in their looking patterns during the test sequence. Analysis of the recovery scores (Table 3) revealed a significant group × test display interaction, $F(1,30) = 4.24$, $p < .05$. Analysis of looking times during the six test trials also revealed a significant habituation group × test display interaction, $F(1,30) = 4.56$, $p < .05$, and no other significant effects. Infants in the rod pieces group looked longer at the complete rod, $t(15) = 2.52$, $p < .025$, whereas those in the rod occlusion group looked longer at the rod pieces, $t(15) = 2.01$, $p < .05$ (one-tailed).

Discussion

After habituation to a partly occluded rod, infants dishabituated to rod pieces with a gap larger than the original occluder. After habituation to the rod pieces behind the same occluder, infants dishabituated to a complete rod. Infants thus looked longer to the test display that differed from the occlusion display with respect to the visible areas of the rod figure.

Taken together, the findings of Experiments 2 and 3 support three conclusions concerning infants' perception of a partly hidden, stationary rod. First, infants who are presented with such a rod perceive the visible surfaces of that object and react to changes in those surfaces. Infants do not attend only to the nearest object in a stationary configuration. If infants had attended only to the nearest object, then those in Experiment 3, habituated to the partly hidden rod, would not have shown greater dishabituation to the rod pieces with the large gap.

The second conclusion is that infants perceive occlusion. When they are presented with a partly hidden object, they perceive its surfaces to continue, indefinitely, behind its occluder. The infants did not perceive the partly hidden rod to end at the places where its occluder began. If they had, then those in Experiment 2 should have generalized from the partly hidden rod to the test figure with the small gap, just as the infants in Experiment 3, habituated to two rod pieces that visibly ended, generalized to the test display with the large gap. The striking difference between looking patterns in these two conditions indicates that a visibly bounded object and a partly occluded object are perceptually quite different for an infant. The occluding edge of the block was not seen as a boundary of the rod.

The third conclusion is that infants do not perceive the visible ends of a partly hidden stationary rod as connected behind the occluder, despite the similarity of those ends in color, texture and shape, and alignment of their edges. In the language of gestalt psychology, infants did not perceive the rod in accordance with the principles of similarity and good continuation.

What did the infants see when they observed the partly occluded rod? The findings of Experiments 2 and 3 suggest that they saw no single, definite object: They did not see a complete rod, or a broken rod, or an object of some other shape. Infants' perception of the hidden surfaces of the stationary rod might be compared to our perception, as adults, of objects and surfaces beyond the limits of the visual field. When we fix our eyes, we do not perceive the visual world to end at the edges of the visual periphery, but neither do we perceive it to continue behind our heads in any particular way. Similarly, infants may perceive the visible surfaces of a partly hidden stationary object, but have no definite impression whether or how these surfaces are connected behind the occluder. Nevertheless, the findings of Experiment 1 indicate that infants' perception of occlusion displays does not always have this indefinite quality. Infants do perceive a connected object when a rod moves as a unit behind its occluder. In the remaining experiments, we ask whether there are other stimulus conditions under which infants perceive a connected object.

EXPERIMENT 4

So far, we have investigated infants' perception of an object with only a moderately "good" shape. It remains possible that infants would perceive the connectedness of a partly hidden stationary object if the object forms a simple, symmetrical, closed figure. Accordingly, Experiment 4 investigated infants' perception of a triangular rod figure whose center was hidden by a block.

The display used in this experiment was patterned after a display that was studied by Michotte and was reported to lead to a compelling impression of a unitary object for adults (Michotte et al., 1964). This display was also used by Bower in experiments with infants, who were reported to perceive a unitary, connected object as well (Bower, 1967).

Method

The method followed that of the preceding experiment, except as noted below.

Subjects

Participants were 48 infants aged 3 months, 15 days, to 4 months, 22 days (mean age: 4 months, 6 days). An additional 19 infants failed to complete the experiment because of fussiness (14 subjects), equipment failure (3 subjects), or experimenter error (2 subjects).

Displays

The occlusion display consisted of a triangle partly hidden by a block. The triangle was equilateral, 38 cm long on each side, made of black dowel rods as in the previous experiments. Its center lay behind a tan block 51 cm long, 13 cm wide, and 4 cm thick. At the infant's viewing distance, the triangle subtended a visual angle of 22.5° per side, and the block subtended about 30° (horizontal) by 8° (vertical).

There were two further triangle and block displays: a complete triangle in front of the block and an incomplete triangle in front of the block. The latter was the same as the complete triangle except for an 11-cm gap in its center. Finally, there were two displays consisting of the complete or the broken triangle with no block present (Fig. 9).

Design and Procedure

One group of 16 infants was habituated to the partly occluded triangle, a second group was habituated to the complete triangle in front of the block, and a third group was habituated to the broken triangle in front of the block. All of the infants were then tested with the complete and with the broken triangles (see Fig. 9).

Interobserver agreement in this experiment ranged from .76 to .98 and averaged .91.

Results

Figure 10 depicts the average course of looking over the habituation and test trials. Infants in the three groups showed similar patterns of habituation. During the test, infants in the complete triangle control group

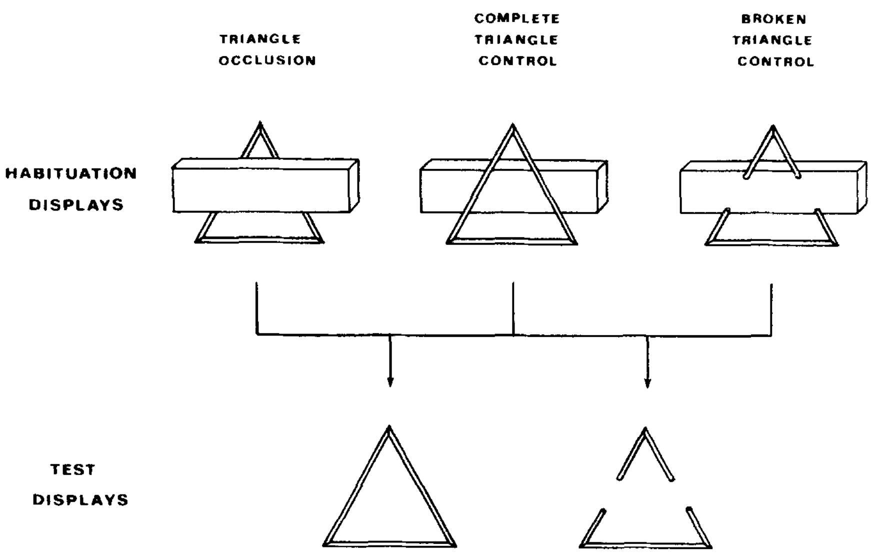

FIG. 9. Displays and design in Experiment 4.

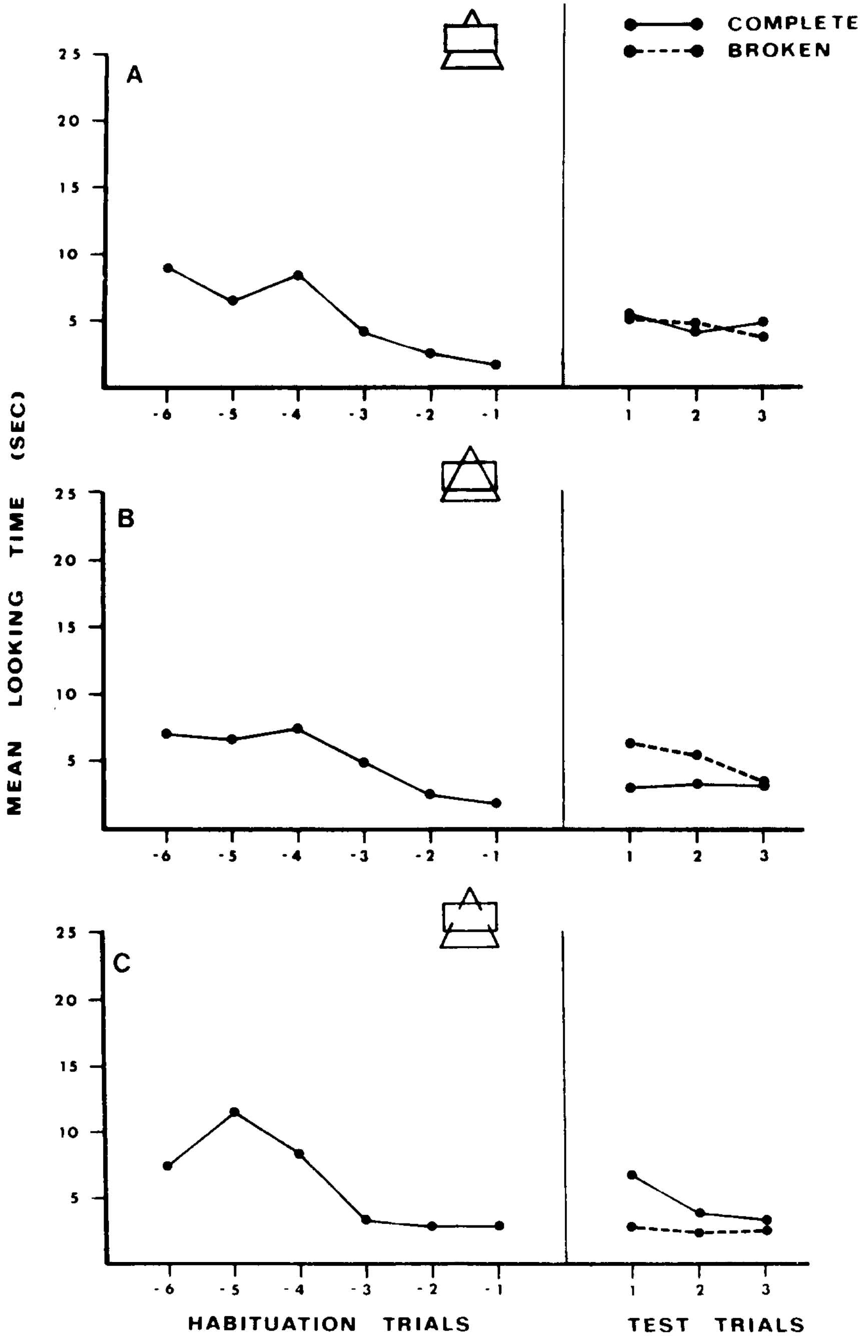

FIG. 10. Looking times in Experiment 4 by infants in (A) the triangle occlusion group, (B) the complete triangle control group, and (C) the broken triangle control group.

appeared to dishabituate only to the broken triangle, those in the broken triangle control group appeared to dishabituate only to the complete triangle, and those in the triangle occlusion group appeared to dishabituate to both test displays.

The analyses confirmed these findings. There were no differences between the groups on any habituation measure, all F's$(2,45) < 1.43$, n.s. The analysis of recovery scores revealed a significant interaction of habituation group and test display, $F(2,45) = 7.14$, $p < .005$ (Table 4). Comparisons across the habituation groups indicated that the degree of recovery shown by the triangle occlusion group best approximated looking to the novel displays by the control groups. Infants in the triangle occlusion group recovered looking to the broken triangle more than did infants in the broken triangle group, $t(30) = 2.27$, $p < .025$, and no less than did infants in the complete triangle group, $t(30) < 1$. Similarly, infants in the occlusion group showed marginally more recovery to the complete triangle than did infants in the complete triangle control group, $t(30) = 1.41$, $p < .10$ (one-tailed), and no less recovery than did infants in the broken triangle control group, $t(30) < 1$.

The analysis of looking times on the six test trials revealed a significant main effect of trial, $F(2,90) = 4.22, p < .05$, reflecting a decline in looking over the three pairs of test trials, and a significant interaction of habituation group by test display, $F(2,45) = 9.77$, $p < .001$. Individual comparisons revealed that infants in the broken triangle control group looked longer at the complete triangle $t(15) = 3.81$, $p < .001$, whereas those in the complete triangle control group looked longer at the broken triangle, $t(15) = 2.87$, $p < .01$. Infants in the occlusion group looked equally to the broken and complete triangles, $t(15) < 1$. Tests for differences in variances between the occlusion group and each of the control groups revealed no differences, both F's$(1,30) < 1.7$, nor were any apparent from inspection of the three distributions of scores. The occlusion group did not consist of two separate subgroups of infants, each dishabituating to one of the test displays.

TABLE 4
Recovery Scores (in seconds) in Experiment 4

	Test display	
Habituation group	Complete triangle	Broken triangle
Triangle occlusion	3.7	3.3
Complete triangle control	1.1	5.1
Broken triangle control	3.9	.1

Discussion

The findings of this experiment agree closely with those of Experiment 2. Infants who were habituated to a partly hidden triangle looked equally to a complete and to a broken triangle. They treated both these displays as novel objects, dishabituating to each of them as much as control infants dishabituated to one figure after habituating to the other. As in Experiment 2, the lack of differential looking by the occlusion group cannot be attributed to floor or ceiling effects, to a failure of discrimination, nor to two distinct subgroups of infants that each dishabituated to one figure. In light of the findings of Experiment 3, the lack of differential looking also cannot plausibly be attributed to a failure to attend to the partly hidden triangle. It appears that the infants neither perceived a complete triangular figure behind the block nor perceived two separate pieces of the figure above and below the block.

In sum, the infants presented with the partly occluded triangle evidently did not perceive it as a unit. To an adult, the continuity of this object follows from the principles of similarity, good continuation, closure, and good form. Infants appear not to perceive partly hidden objects in accordance with these principles. Our findings do not agree with those reported by Bower (1967).

EXPERIMENT 5

In the next experiments, we focus on the effects of motion on perception of a partly hidden object. Although Experiment 1 indicated that infants perceive a partly hidden rod as continuing behind its occluder, the experiment did not reveal what aspects of the movement pattern led to this effect. Did perception of a complete rod depend on detection of the movement of the rod relative to the block, detection of the rod's movement relative to the background and to the infant, or detection of both kinds of relative displacement? To address this question, Experiment 5 compared infants' perception of a partly hidden rod when the rod moved, the block moved, both moved, or neither moved.

The experiment used rod and block displays, as in Experiments 1 and 2. In one condition, the block moved in front of a stationary rod. In a second condition, the rod and block moved together. These conditions were compared with each other and with the experimental conditions of Experiment 1, in which the rod moved behind the stationary block, and Experiment 2, in which the rod and block were stationary. With such comparisons, we sought to determine what aspects of movement provide infants with information about the boundaries of objects.

Method

The method was the same as in the preceding experiments, except as follows.

Subjects

Participants were 32 infants aged 3 months, 15 days, to 4 months, 16 days (mean: 3 months, 27 days). An additional 13 subjects failed to finish the experiment because of fussiness (9 infants), equipment failure (2 infants), experimenter error (1 infant), or parental interference with the experiment (1 infant). The 32 infants in the experimental conditions of Experiments 2 and 3 also contributed to the analyses of the present experiment.

Displays

The displays for the two new conditions consisted of the partly occluded rod and the block. They differed only with respect to the movement of the objects. In one display, the rod and block moved in tandem. In the other display, the rod was stationary and the block moved in front of it. The moving objects underwent a lateral translation, back and forth against the stationary background. They traversed 15 cm from side to side at a real velocity of 7.5 cm/sec (angular velocity: 4.5°/sec), pausing .5 sec at each end of the trajectory. No object moved far enough to expose the center of the rod to view.

In addition to these occlusion displays, there were four displays consisting only of rod figures. The complete and broken test rods of the earlier experiments were presented either stationary or in motion. In the latter case, the rods moved laterally as in the above displays. All the displays are depicted in Fig. 11.

Design and Procedure

There were 16 infants in each of four habituation conditions: rod and block movement, block movement, rod movement (Experiment 1), and no movement (Experiment 2). After habituation, each infant was tested with a broken and a complete rod. Moving test rods were presented to infants who were familiarized with moving rods, and stationary test rods were presented to infants who were familiarized with stationary rods (see Fig. 11).

Interobserver agreement in this experiment ranged from .68 to .97 and averaged .87.

Results

The principal results are depicted in Fig. 12. During the habituation trials, looking times to the occlusion display appeared to be highest for infants in the rod movement group and lowest for infants in the block movement and the no movement groups. During the test, infants in the rod movement group showed greater recovery to the broken rod. Infants in each of the other groups showed equal recovery, or lack of recovery to the two test displays.

Analyses indicated that the four groups did not differ with respect to the number of trials to habituation but did differ with respect to the other three habituation measures (Table 5). Infants in the rod movement group looked longer than infants in the block movement and no movement groups on all three of these measures. They looked longer than infants in the rod and block movement group on the mean looking time measure and on the measure of looking time on the first habituation trial. Infants in the rod and block movement group, the block movement group, and the no movement group did not differ on any measure.

The analysis of the recovery scores revealed a main effect of habituation group, $F(3,60) = 5.77$, $p < .005$: Recovery scores were higher for

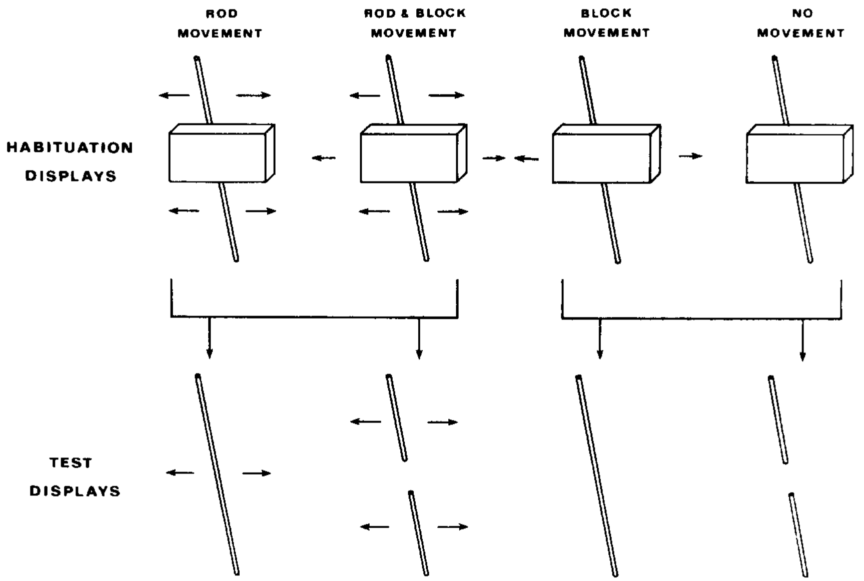

FIG. 11. Displays and design in Experiment 5.

the groups presented with moving rods than for the groups presented with stationary rods. There was also a main effect of test display, $F(1,60) = 7.28$, $p < .01$, indicating greater recovery overall to the broken rod. Most important, there was an interaction of habituation group × test display, $F(3,60) = 5.65$, $p < .001$ (see Table 6). This interaction is best understood by considering separately the recovery patterns of infants presented with moving and with stationary test displays.

Rod and Block Movement Group and Rod Movement Group

Recall that the infants in the rod movement group (Experiment 1) showed greater recovery to the broken rod than to the complete rod, $t(15) = 3.32$, $p < .005$. Indeed they appeared to show no recovery to the complete rod. In contrast, the infants in the rod and block movement group showed equal recovery to the complete and broken test rods, $t(15) < 1$. Their recovery was intermediate in magnitude to that of infants in the rod movement group: They showed greater recovery to the complete rod than the rod movement group, $t(30) = 1.78$, $p < .05$ (one-tailed), and less recovery to the broken rod, $t(30) = 1.89$, $p < .05$ (one-tailed).

Block Movement and No Movement Groups

These infants showed equal recovery to the complete and broken rods, both t's$(15) < 1$. Recall that infants in the no movement group (Experiment 2) appeared to treat both test displays as novel objects, as indicated by their substantial recovery scores relative to control group infants in

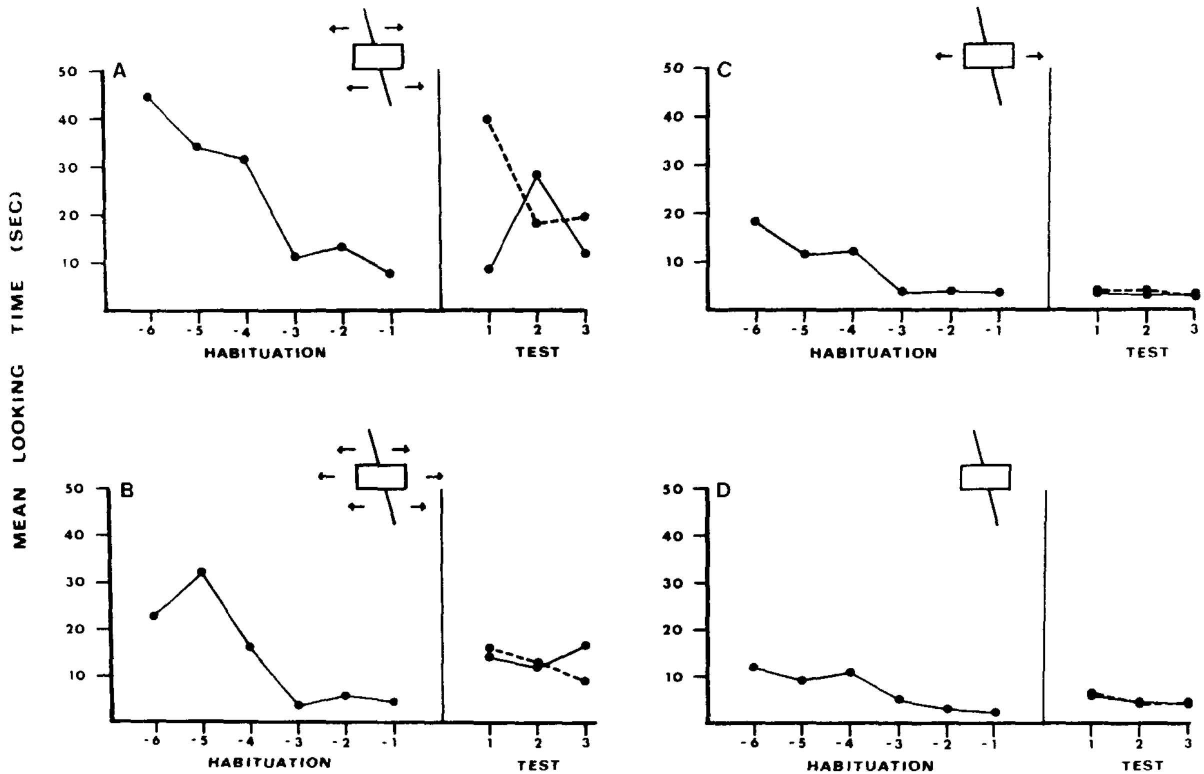

FIG. 12. Looking times in Experiment 5 by infants in (A) the rod movement group (from Experiment 1), (B) the rod and block movement group, (C) the block movement group, and (D) the no movement group (from Experiment 2).

Experiment 2. In contrast, infants in the block movement group showed little recovery to the test displays: Compared with infants in the no movement condition, they exhibited less recovery to the broken rod, $t(30) = 2.08$, $p < .025$, and marginally less recovery to the complete rod, $t(30) = 1.53$, $p < .10$. These low recovery scores may, however, be an artifact. These infants were habituated to moving displays and then tested with stationary displays. The change from a moving to a motionless display may have produced an overall drop in looking times during the test.

The analysis of looking times on the six test trials yielded a complex pattern of findings. There was a significant main effect of habituation group, $F(3,60) = 8.37$, $p < .001$: Infants presented with moving test displays looked at them longer than infants presented with stationary test displays. In addition, there was a habituation group × test display interaction, $F(3,60) = 3.70$, $p < .025$, and a three-way interaction of these factors with trial block, $F(6,120) = 4.13$, $p < .001$. The two-way interaction reflects the fact that the rod movement group showed a reliable preference for the broken rod, $t(15) = 2.34$, $p < .025$, whereas the other three groups showed no such preference, all t's$(15) < 1$. The three-way interaction was also produced primarily by infants in the rod movement group: They looked longer at the broken rod on the first pair of test trials, $t(15) = 3.32$, $p < .005$, showed no difference in looking time on the second pair of trials, $t(15) = -1.31$, n.s., and showed a marginally significant tendency to look longer at the broken rod on the third pair of test trials, $t(15) = 1.74$, $p < .10$ (one-tailed). There were no significant preferences between the test displays for any other group on any pair of trials, all t's$(15) < 1.2$.

Discussion

When infants were presented with a partly hidden rod and block that moved together, or with a rod that was stationary behind a moving block, they did not appear to perceive the visible parts of the rod as connected behind the block. Infants perceived the connectedness of a partly hidden rod only when it moved behind a stationary occluder. The findings of Experiments 1, 2, and 5 suggest that the essential aspects of motion include movement of the occluded object relative to both the occluding object and the background.

The explanation for the findings of Experiments 1, 2, and 5 might be quite straightforward. Infants may perceive a connection between two visible surfaces in a scene whenever (a) the surfaces are separated by no visible gap—no visible region of empty space—and (b) the surfaces undergo a common movement relative to the background and the infant. Thus, infants will perceive that the two ends of a rod are connected behind the occluder when the ends move together and the occluder is

TABLE 5
Characteristics of Habituation in Experiment 5

	Group				
	Rod movement	Rod and Block movement	Block movement	No movement	$F(3,60)$
Trials to habituation (number)	7.6	9.9	8.2	10.4	1.14
Total looking time in the habituation period (sec)	172.9	114.5	72.0	73.5	5.13**
Mean looking time per trial in the habituation period (sec)	25.3	14.5	9.6	7.8	5.82**
Duration of looking on the first habituation trial (sec)	46.1	22.2	20.2	11.2	3.99*

Note. Newman–Keuls tests were performed on the three measures showing a significant effect. Means underlined by a common line do not differ (.05) by these tests.
* $p < .025$.
** $p < .01$.

TABLE 6
Recovery Scores (in seconds) in Experiment 5

	Test display	
Habituation group	Complete rod	Broken rod
Rod movement	.6	32.2
Rod and block movement	9.9	11.7
Block movement	.2	.4
No movement	3.5	4.6

stationary. When the block moves with the rod parts, however, the infants may perceive the rod and block as a single object since the common movement will unite all three visible surfaces. Thus, they will not perceive the rod itself as a distinct object. Finally, when the rod parts are stationary, infants will not perceive them as connected, whether or not the block moves, since the rod surfaces undergo no common movement.

The above account of the effects of movement makes no reference to the configurational properties of a moving object: the similarity of its surfaces in color and texture, or the goodness of its form. It is possible, however, that configurational properties do have some effect on perception of moving occlusion displays. Infants may perceive the complete shape of a partly hidden moving object only when the object is uniformly colored or simply shaped. The next experiment investigated this possibility.

EXPERIMENT 6

Infants in an experimental group were habituated to an occlusion display in which two nonaligned surfaces, of different colors and textures, moved together. The infants were subsequently tested with displays in which these surfaces were either connected or not connected. Their looking times to the test displays were compared with the looking times of infants in a baseline group, who viewed the test displays after habituating to different objects. If common movement alone leads infants to see two partly hidden surfaces as connected, infants in the experimental group should have shown marked dishabituation to the test display with the gap. If configurational properties also affect perception of partly occluded objects, then infants in the experimental group should not have shown as marked a pattern of dishabituation to the display with a gap as did the infants in Experiment 1, who were presented with a moving object of a uniform color and simple shape.

Method

The method of Experiment 6 differed from the earlier studies only as follows.

Subjects

Participants were 32 infants aged 3 months, 15 days, to 4 months, 23 days (mean age: 4 months, 4 days). An additional 9 subjects began the experiment but failed to complete it because of fussiness (7 infants) or equipment failure (2 infants). The 16 infants in the experimental condition of Experiment 1 also contributed to some of the analyses.

Displays

The principal display consisted of a black rod, a randomly shaped polygon painted red with black speckles, and a tan occluding block. The black dowel rod used in the previous studies appeared above the top of the block. The red polygon appeared below it. The polygon was designed randomly within certain constraints (following Attneave & Arnoult, 1956), and was oriented so that neither its edges nor its major axis was aligned with those of the rod. This display measured a total of 53 cm in height; the rod was again 1.3 cm in diameter, and the polygon was 10 cm at its widest part. The block measured 13 × 25 cm. At the infant's point of observation, this display subtended 33.5° (height), .75° (rod width), 6° (polygon width), and 15.5° (block width). As in the preceding experiments, the rod and polygon were suspended 10 cm in front of the white pegboard background and the block was suspended an additional 5 cm in front of them.

In addition to this display were two displays in which the rod and polygon appeared with no block present. In one, the rod and polygon formed a single connected object. This display was constructed by continuing the polygon upward with random turns (again following Attneave & Arnoult, 1956) and continuing the rod downward until they met in the center

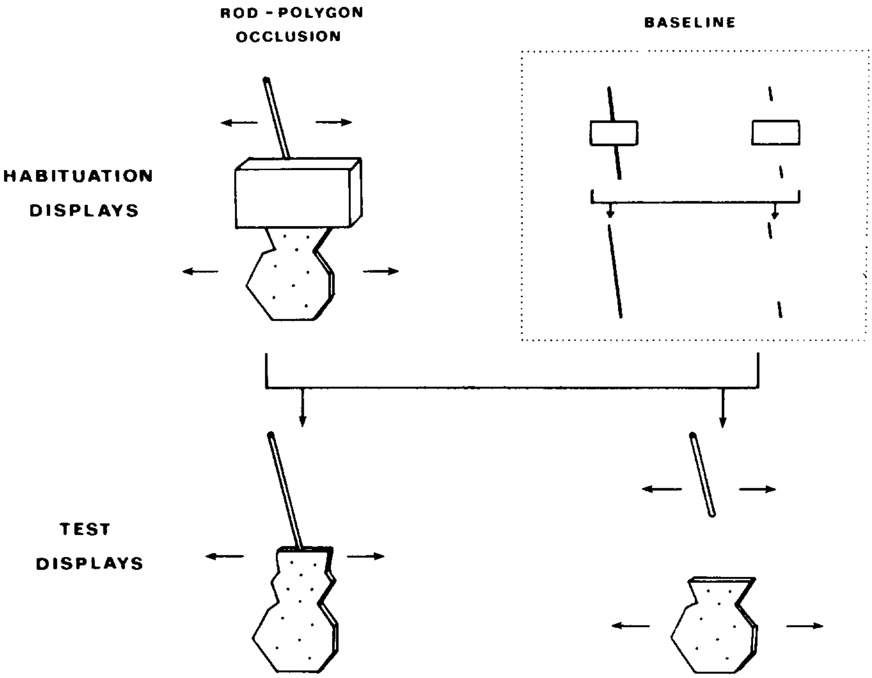

FIG. 13. Displays and design in Experiment 6.

of the display. At the place where the rod and polygon were joined, the polygon sloped forward so that the connection was visible to the infant. In the other display, the rod and polygon were separated by a 10-cm gap.

In each of these displays, the rod and polygon moved laterally in tandem. They underwent the same movement as did the rod in Experiment 1. These displays are depicted in Fig. 13.

Design and Procedure

Infants participated in two habituation conditions. Those in one condition were habituated to the moving rod–polygon occlusion display; those in a second, baseline condition were habituated to an unrelated occlusion display (see below). After habituation, both groups of infants were presented with the connected and the unconnected rod and polygon displays, with no occluding block, for six alternating test trials.

The habituation period for the baseline group was designed to acquaint infants with the general experimental procedure and apparatus and with partly occluded objects, without familiarizing them specifically with the displays to be tested. Accordingly, these infants participated first in a complete habituation experiment, in which they viewed the partly occluded rod and the rod pieces displays of Experiment 3. Specifically, the infants in the baseline group constituted 8 of the 16 subjects in each of the conditions of Experiment 3. After the close of that experiment, infants in the baseline group were presented with the connected and the unconnected rod and polygon displays. Analyses revealed that the baseline group's looking times to the rod–polygon displays were unaffected by their habituation condition during the familiarization period.

Interobserver agreement during the habituation trials (experimental group only) and the test trials (both groups) ranged from .76 to .97 and averaged .88.

Results

Figure 14 depicts the course of looking during the habituation and test trials for the rod–polygon movement group, and the course of looking during the test trials for the baseline group. Infants in the rod–polygon group habituated to the occlusion display, and then they looked longer at the unconnected rod and polygon than at the connected rod and polygon. Infants in the baseline group looked about equally to the two rod and polygon displays.

The analyses confirmed these impressions. Patterns of habituation for infants in the rod–polygon movement group were compared with those of infants in the rod movement group of Experiment 1. There were no significant differences between these conditions, all t's$(30) < 1$. No recovery scores can be calculated for infants in the baseline group, but recovery scores were calculated for infants in the rod–polygon movement group. These infants showed greater recovery to the unconnected display, $t(16) = 3.11$, $p < .005$ (Table 7). The recovery scores of infants in the rod–polygon movement group were compared to those of infants in Experiment 1. The only significant effect in this analysis was a main effect of test display, $F(1,30) = 18.84$, $p < .001$. Infants in both conditions showed greater recovery to the broken test display. The degree of recovery to the broken display did not differ across the two experiments.

The analysis of looking times on the six test trials compared the rod–polygon movement group with the baseline group. This analysis revealed a main effect of trial, $F(2,60) = 11.91$, $p < .001$, a group $\times$ trial interaction, $F(2,60) = 3.85$, $p < .05$, and a marginal interaction of group $\times$ display $\times$ trial, $F(2,60) = 2.39$, $p < .10$. The effects of trial and group $\times$ trial reflect the sharp drop in total looking time over the course of the test trials and the greater uniformity of this drop in the baseline condition. Concerning the three-way interaction, individual comparisons revealed that infants in the rod–polygon movement group looked longer to the unconnected object on the first trial, $t(15) = 3.11$, $p < .005$, and showed no preferences between these displays on the other trials, both t's$(15) < 1$. Infants in the baseline group showed no preferences between these displays on any trials, all t's$(15) < .74$.

Discussion

When infants viewed two dissimilar, nonaligned surfaces moving together behind an occluder, they appeared to perceive those surfaces as connected behind the occluder. After habituation to this display, infants showed greater recovery to a display in which the surfaces were not connected. This difference is not due to any greater intrinsic attractiveness of the unconnected objects, since a baseline group showed a slight (nonsignificant) looking time advantage in the opposite direction. The

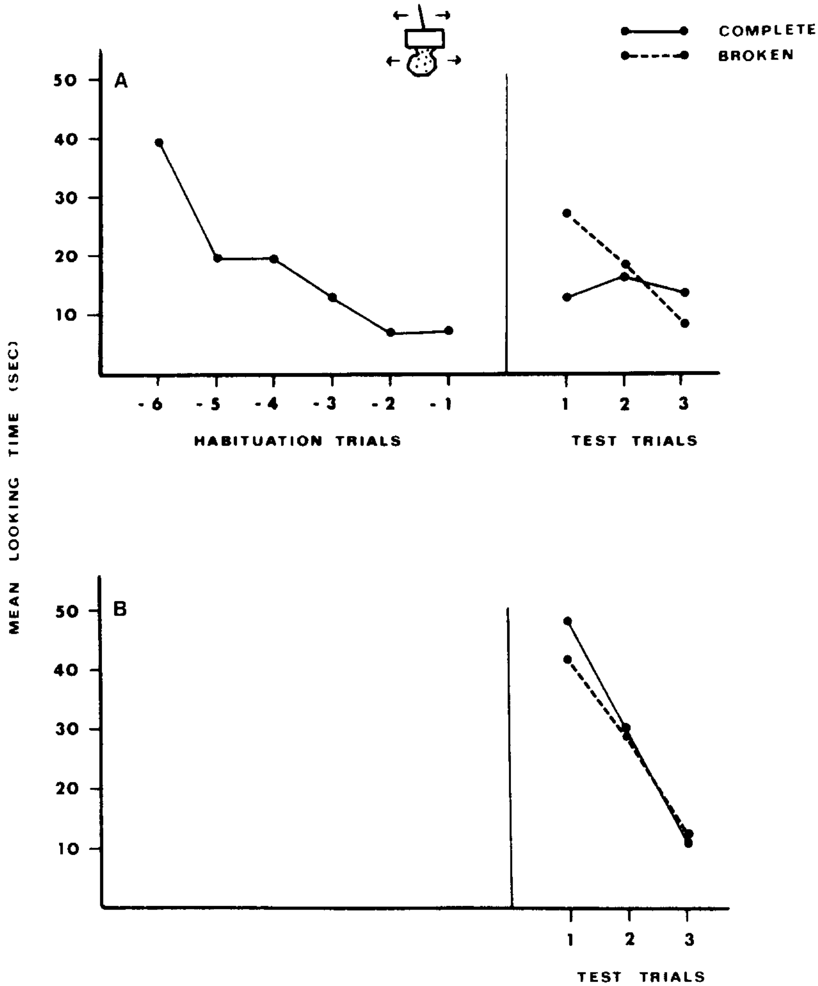

FIG. 14. Looking times in Experiment 6 by infants in (A) the rod–polygon occlusion group, and (B) the baseline group.

TABLE 7
Recovery Scores (in seconds) in Experiment 6

	Test display	
Habituation group	Complete rod–polygon	Broken rod–polygon
Rod–polygon movement	5.4	19.6
Rod movement[a]	.6	32.2

[a] The rod movement group from Experiment 1 is shown here for comparison (see text).

degree of recovery to the unconnected rod and polygon was just as great as the degree of recovery to a broken rod, shown by infants who had been habituated to a uniform rod moving behind the occluder.

This experiment provides further evidence that infants' perception of a partly hidden object is not affected by the simplicity or regularity of its color or shape. Perception of such an object only appears to be affected by its pattern of movement. Infants perceive two ends of an object as connected behind an occluder if the ends undergo a common lateral translation, whether or not the ends are uniformly colored, aligned, and simply shaped. Only movement appears to lead infants to perceive a partly hidden object as continuing behind its occluder.

EXPERIMENT 7

To investigate how infants' perception of partly occluded objects compares with that of adults, a final experiment was undertaken. College students were presented with the principal displays shown to infants. They were asked to rate the strength of their impression that two partly occluded surfaces were connected behind an occluding block.

Method

Subjects

Ten undergraduates at the University of Pennsylvania were paid for their participation. None of the subjects had taken a course in perception.

Displays

Subjects were presented with the 10 displays depicted in Fig. 16. Six of these displays were the same as those shown to infants: the rod movement display, the stationary rod display, the stationary triangle display, the rod and block movement display, the block movement display, and the rod–polygon movement display. Three further displays were designed to evoke perception of two separate objects: a stationary rod–polygon display and two displays in which partly occluded surfaces moved independently of each other. One further display consisted of a rod moving in depth. The subjects viewed these figures in the same display box and from the same distance as did infants.

Design

Each subject was shown all 10 displays in a different order. A 10×10 Latin square was devised which placed each display in each presentation position equally often and also ensured that each display preceded and followed each other display exactly half the time.

Procedure

Subjects were asked to rate the apparent connectedness of the surfaces behind the block. In order to assess their perceptual impressions, rather than their ability to imagine possible artifice, a brief demonstration was given before the experiment. Subjects were shown a rectangular writing tablet lying atop a pencil and a square of light blue paper. The latter objects were positioned so that the three corners of the square emerged from beneath three different edges of the tablet. Figure 15 depicts this display. The Experimenter said, "This is a study of the way people perceive partly hidden objects under varying conditions. You will be shown ten displays and asked to give your impression whether two visible parts are connected or not connected behind a block which occludes them in each case. To give you an idea of the kind of impression we will be asking about, look at this display (pointing to Fig. 15). Does this part of the world (pointing to one blue corner) seem to be connected to this (pointing to the pencil end) or to this (pointing to another blue corner)?" All subjects replied that only the corners seemed connected. The experimenter then asked, "Do you have any impression of the shape of the object that the two blue parts belong to?" All subjects said that it was a square. "Good. That is the kind of impression, of whether things are connected in partly hidden areas, that you will be asked to give for each of the 10 displays. Each time you will fill out one of these sheets, rating the strength of your impression of connectedness or disconnectedness." Subjects were given a booklet of 10 identical sheets. Each sheet had the following instructions typed on it:

Strength of Impression

> Indicate the strength of your impression of the display. If you are certain that there is a single object behind the block (that is, the visible parts are connected), mark "4". If you are certain that there are two separate objects behind the block (that is, the visible parts do not connect), mark "−4". If both impressions are readily achieved or neither impression occurs, mark "0". If you tend to see the display one way, but are not completely certain, pick one of the other numbers. The stronger your impression is, the closer to 4 or −4 you should pick.

The 10 displays were shown to each subject for 3 sec each. About 1 min elapsed between each presentation while the experimenter changed the displays.

Data Analysis

The rating for each display was compared to the neutral point of 0 by a z score. Mean ratings of the displays were compared with each other by a one-way ANOVA.

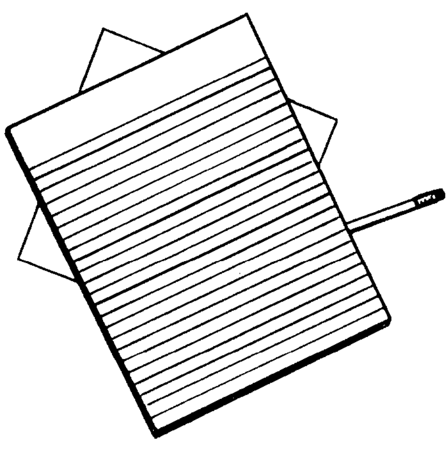

FIG. 15. Preexperimental demonstration in Experiment 7.

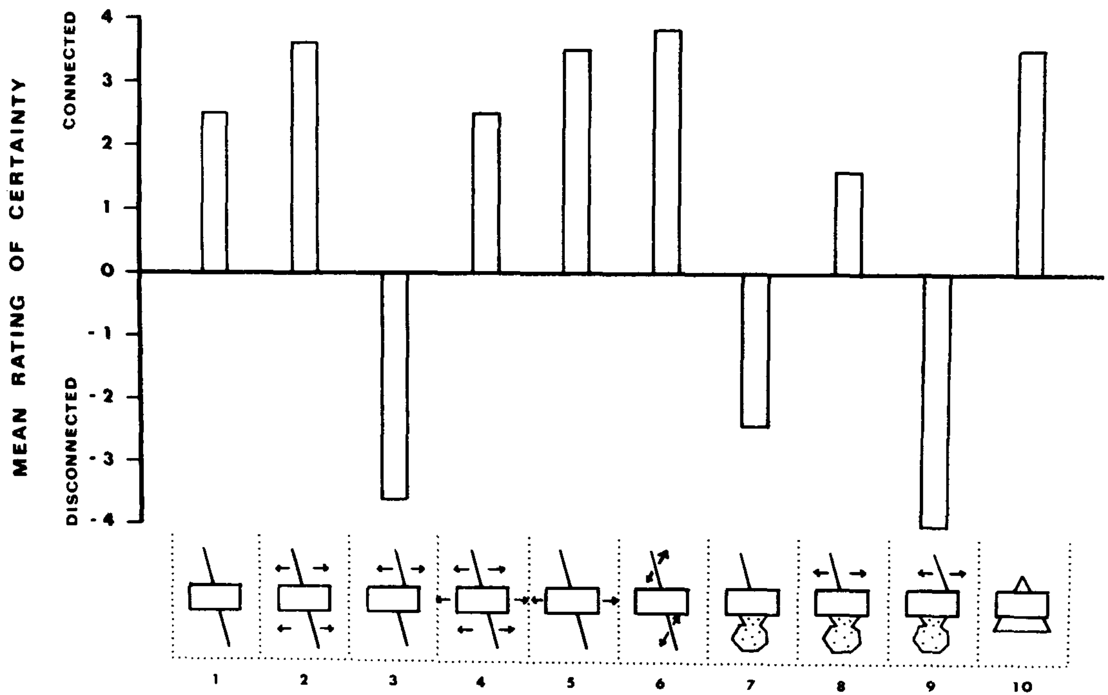

FIG. 16. Connectedness ratings of the occlusion displays by adults in Experiment 7. (All horizontal arrows indicate lateral translation; oblique arrows indicate translation in depth.)

Results and Discussion

Figure 16 shows the mean rating given to each partly occluded object. Each of these ratings differed reliably from the neutral point of 0, all z's > 3.20, $p < .001$. All the rods, the triangle, and the moving rod–polygon were given positive ratings, and thus were judged to be connected behind the occluder.

There were reliable differences between the rated strength of impressions of connectedness for different displays, $F(9,81) = 87.9$, $p < .001$. For present purposes, the most important differences were these: (1) the stationary triangle received a higher rating of connectedness than the stationary rod, $t(9) = 2.09$, $p < .05$ (one-tailed), indicating the effects of good form and/or closure; (2) the moving rod received a higher rating than the stationary rod, $t(9) = 2.29$, $p < .025$, indicating the effects of movement; and (3) the moving rod–polygon received a lower rating than both the moving rod, $t(9) = 4.07$, $p < .005$, and the stationary rod, $t(9) = 1.88$, $p < .05$ (one-tailed). Indeed, the moving rod–polygon received the lowest rating of any display in which a unitary object was perceived.

How strong are the effects of kinetic and static configurational properties on the adult's perception of partly hidden objects? This question may not be answerable in general; depending on the particular kinetic and configurational properties selected, different orderings of these variables might be obtained. Considering only the displays used in the present experiments, however, it is clear that the goodness of an object's form and the uniformity of its color had a substantial effect on perception of the connectedness of its visible surfaces. In this respect, adults perceived these displays differently from infants. Static configurational properties had no evident effect on infants' perception.

GENERAL DISCUSSION

In brief, our experiments support three conclusions about infants' perception of partly hidden objects. First, infants can perceive one surface going behind another: An object is not perceived to end where a nearer object occludes it. In no experiment did habituation generalize from a partly occluded object to two disconnected objects with a gap in the area that had been occluded. An object boundary and a surface interrupted by occlusion are different in the infant's visual world.

Second, infants perceive the visible parts of an object as connected if they move together behind a stationary occluder. When a rod or a rod and polygon moved together behind a stationary block, habituation to that display generalized to a connected rod or rod–polygon and not to a corresponding figure with a gap. Infants evidently perceive the unity of a partly hidden object, as long as it moves relative to its surroundings.

Third, young infants do not perceive partly hidden objects by analyzing the colors, textures, or shapes of surfaces. When infants were presented with a partly hidden stationary object of a simple shape and a regular color, they did not perceive it as a unitary, connected object. Habituation to such an object was followed by equal dishabituation to a complete object and to a broken object. Moreover, perception of the unity of a moving object was unaffected by the regularity of that object in color, texture, and shape. Habituation to a moving rod and polygon produced the same preference for a broken display as did habituation to a moving rod. Infants do not appear to use the configural properties of a scene as information about the unity and boundaries of partly hidden objects. In this respect, infants differ from adults.

The findings of these experiments provide evidence against the thesis, first proposed by gestalt theorists, that perception of objects emerges as a consequence of a general tendency toward simplicity. One could describe the findings of our experiments in the language of gestalt psychology, by stating that infants perceive in accordance with the principle of common fate but not the principles of similarity, good continuation, and good form. To do this, however, is to overlook the central claim of gestalt theory. According to the gestalt psychologists, the various principles of organization are diverse surface manifestations of a single, underlying property of nervous activity and of the experiences to which this activity gives rise: a tendency toward simplicity. The finding that infants perceive objects in accordance with one manifestation of this tendency but not others casts doubt on the claim that any such general tendency underlies perception of objects. It is possible that humans do have an innate preference for "simple" configurations. This tendency may even be present in early infancy, and it may lead young infants to perceive some forms as "better" than others (see Bornstein, Ferdinandsen, & Cross, 1981; Bomba & Siqueland, 1983). But young infants do not appear to use the regularity or simplicity of configurations as information about the boundaries of objects.

These experiments also provide evidence against Piaget's theory that object perception develops slowly over the 1st year through the coordination of action. Four-month-old infants are able to act on objects only in extremely limited ways. As Piaget's detailed observations attest, many important sensory–motor coordinations are lacking: 4-month-old infants cannot apprehend objects by reaching and grasping, or search for them by locomoting or by displacing occluding surfaces (Piaget, 1952). Indeed, these infants lack most of the coordinations Piaget believed were essential for object perception (Piaget, 1954). Nevertheless, the 4-month-old infants in our experiments never perceived the visible surfaces of a partly hidden object as distinct regions of a scene, as proposed by Piaget and, indeed, by generations of empiricists. Under conditions involving movement, moreover, these infants perceived the unity and complete form of a partly hidden object. These considerations cast strong doubt on Piaget's account and related contemporary accounts (Harris, 1983) of both the timing and the causes of the emergence of the ability to perceive partly hidden objects. It is very unlikely that object perception develops through the coordination of action. Although actions on objects do develop and become progressively coordinated, infants appear to perceive objects before much of this development takes place.

Our findings are consistent with a third view which roots perception of partly hidden objects in an unlearned conception of the physical world (Spelke, 1983). Humans may begin life with the notion that the environment is composed of things that are coherent, that move as units independently of each other, and that tend to persist, maintaining their coherence and boundaries as they move. This notion would lead infants to expect, on some level, that partly hidden surfaces undergoing common movement are connected. But infants should not expect surfaces to be connected by virtue of the regularity of their colors and textures, or the goodness of the forms that can be created by grouping them together. For infants, on this view, do not conceive of the world as composed of things that tend to have simple shapes and uniform substances.

This view is supported by the findings of a number of further experiments. For example, experiments suggest that infants under 6 months perceive two adjacent objects as distinct when one moves relative to the other (Piaget, 1954), but not when the objects are stationary (Piaget, 1954; Prather & Spelke, 1982; Spelke & Born, in preparation; see also Bresson & de Schonen, 1976–1977; Wishart, 1979). These findings provide further evidence that infants perceive objects by detecting the movements of surfaces and not by analyzing the colors or forms of surfaces. The findings are consistent with the view that infants conceive of objects as coherently and separately moveable.

Other recent research suggests that young infants expect a fully visible object to persist as a connected unit when surfaces move within a scene. They expect an object to move as a unit when it is displaced within the infant's view (Spelke & Born, in preparation), and they expect it to persist as a unit, in a definite place, when other surfaces move so as to carry it fully out of view (Baillargeon & Spelke, in preparation).

Finally, studies of the young child's earliest counting and word learning suggest that these activities depend in part on the detection of the spatial arrangements and the movements of surfaces and on the grouping of these surfaces into objects (Gelman & Gallistel, 1978; Gleitman, personal communication). Toddlers readily count and learn new words for connected, bounded objects; they are much less apt to count or communicate about arbitrary parts of an object or arbitrary configurations of several objects. These observations suggest that a conception of objects develops naturally and spontaneously in infancy, and that it is intimately related to the infant's ability to perceive organization in the world and to learn about the world (see Spelke, 1983; Gibson & Spelke, 1983).

The conception of objects that we would attribute to infants would appear to be the central conception of objects that humans hold as adults. When adults encounter some body of matter, we tend to consider it an object if it is coherent and moveable, even if it is highly irregular in shape and substance. We would be far less likely to consider such matter an object, however, if it consisted of several separate and separately moveable bodies. Uniformity of shape and substance are characteristic, but not essential, properties of objects. Coherence over movement may be an essential property, at the center of our conception of the world.[6]

If this view is correct, then knowledge of material objects may be one domain of cognition, perhaps one of many, in which our knowledge is elaborated with development, but is never fundamentally reorganized. A child who first conceives of the world as composed of coherent and moveable things will tend to focus on such things to perceive and to learn about. It is perhaps through learning that children come to know that coherent, moveable things tend to be regular in shape and color and that certain of these things belong to certain kinds, like cats and telephones. But objects—unitary, persisting, moveable things—are what children will learn about. Our original conceptions thus will tend to perpetuate themselves in everything we learn, and will remain our deepest conceptions of the world. Studies of infancy should help reveal what those conceptions are.

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[6] It is interesting to note in this regard that recent work in computational theories of vision (Marr, 1982) suggests that this notion is mirrored in a basic constraint operating in binocular depth perception. Stereoscopic depth can be extracted unambiguously from random dot patterns only on the "assumption" that surfaces are continuous (except at object boundaries). Four-month-old infants have been shown to perceive stereoscopic depth in such random dot displays (Fox, Aslin, Shea, & Dumais, 1980).

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