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Object Perception in Infancy: Interaction of Spatial and Kinetic Information for Object Boundaries

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Infants' perception of object boundaries was studied using reaching and preferential looking methods. In 3 reaching studies, 5-month-old infants viewed 2 adjacent or separated objects that were stationary, moved together, or moved separately. Infants reached for the objects as distinct units when they moved separately or were separated in space and otherwise reached for the objects as 1 unit. In the looking study, 3-month-old infants were habituated to adjacent or separated objects alternately moving together and separately and were then tested with objects in the other spatial relationship. Patterns of dishabituation provided further evidence that separated or separately moving objects were perceived as distinct units. Infants appear to analyze surface arrangements and motions to form spatially connected bodies that move as wholes. This tendency may stem from an initial conception of the physical world.

Human adults organize the world into objects: entities with internal unity, external boundaries, and stability through time. Recent experiments provide evidence that young infants perceive objects as well. Like adults, infants can perceive the unity and boundaries of objects by analyzing the three-dimensional arrangements and the three-dimensional motions of surfaces.

Infants have been found to perceive objects in stationary displays by detecting the spatial connections and separations between surfaces. In a series of studies using a habituation method (Kestenbaum, Termine, & Spelke, 1987; Prather & Spelke, 1982; see Spelke, 1985a, for a review), the dishabituation patterns of 3-month-old infants provided evidence that the infants perceived two stationary objects as distinct units if the objects were spatially separated, either vertically or in depth. In contrast, the studies provided evidence that two stationary objects were perceived as a single unit if they touched, either vertically or in depth. Adjacent objects were perceived as a single unit, even when the boundary between them was marked by gestalt factors such as differences in texture and surface coloring and misalignment of edges.

In further studies using a reaching method (Hofsten & Spelke, 1985), 5-month-old infants were found to reach for the smaller and closer of two stationary objects if the objects were spatially separated in depth. If the objects were adjacent in depth, in contrast, the infants reached for the outer contours of the whole structure, grasping it by the edges of the larger, more distant object or by the edges of both objects simultaneously. Given infants' tendency to reach for the closer of two objects and to reach for objects by grasping their external borders (see below), these reaching patterns provided evidence that infants perceived the separated objects as two distinct units and the adjacent objects as one unit. All these experiments support the conclusion that infants perceive object boundaries by detecting surface separations.

In moving displays, infants have been found to perceive objects by detecting patterns of surface motion: Infants perceive surfaces as lying on distinct objects if the surfaces move relative to one another, and they perceive surfaces as lying on a single object if the surfaces move rigidly together. The latter tendency is manifest in a situation in which the spatial connections or gaps between surfaces are hidden behind an occluder. After 4-month-old infants were habituated to two partly visible surfaces that moved together above and below a central occluder, their patterns of dishabituation to fully visible displays provided evidence that the infants perceived the surfaces as lying on a single object that was connected behind the occluder (Kellman & Spelke, 1983). A unitary object was perceived whenever the surfaces underwent a common translatory motion, either laterally or in depth (Kellman, Gleitman, & Spelke, 1987; Kellman, Spelke, & Short, 1986). In contrast, patterns of dishabituation provided evidence that infants did not perceive such surfaces as connected if the surfaces were stationary, even if that connection was marked by gestalt factors such as sameness in surface coloring, alignment of edges, and goodness of overall form (Kellman & Spelke, 1983; Schmidt & Spelke, 1988; Schmidt, Spelke, & LaMorte, 1986; Schwartz, 1983; Termine, Hrynick, Kestenbaum, Gleitman, & Spelke, 1987).

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Thus, spatial relationships among surfaces influence object perception in the absence of motion, and kinetic relationships among surfaces influence object perception in the absence of visible connections or gaps. How do these sources of information interact when both are available? One of the first observations on this topic was made by Piaget (1954). Piaget presented a matchbox to his infant son and then placed it on a book. Between 6 and 10 months, the infant typically ignored the matchbox and grasped the book. On one occasion, however, the book was tilted, and the matchbox started to slide over its surface. The infant immediately grasped the matchbox, suggesting that the motion of the matchbox relative to the book led the infant to perceive the two adjacent objects as distinct.

This suggestion is supported by recent studies of object-directed reaching, in which 5½-month-old infants were presented with two adjacent objects undergoing different patterns of motion (Hofsten & Spelke, 1985). Although the infants tended to reach for the two objects as a single unit when the objects were stationary or moved rigidly together, they tended to reach for the closer of the two objects as a separate unit when the objects moved relative to each other. The latter pattern was observed even when the closer object was stationary and the more distant object moved behind it. This finding provides evidence that infants perceive adjacent objects as distinct units if one object moves relative to the other.

What do infants perceive when two objects move together but are separated? Does their common motion unite them, despite their spatial separation? Hofsten and Spelke (1985) presented infants with two objects that were separated in depth and that were either stationary or moved together. Although the infants reached for the closer object as a distinct unit when the objects were stationary, they reached for the two objects as a single unit when the objects moved together. In this situation, therefore, kinetic information prevailed over spatial information and specified that the objects formed a single unit.

The findings of Hofsten and Spelke (1985) suggest that motion is a powerful source of information for object unity. The findings do not indicate, however, that common motion will always unite surfaces perceptually. It is possible that common motion will only unite surfaces whose spatial connections or separations cannot be seen directly, as is the case when surfaces stand behind a common occluder or are arranged in depth. More generally, perception of objects might depend on a tendency to group surfaces into bodies that are *cohesive:* connected units that maintain their connectivity as they move (Spelke, 1988). Motion would provide infants with information about the hidden connections between surfaces that are arranged in depth, as in Hofsten and Spelke's (1985) experiments, or surfaces that are partly hidden behind a common occluder, as in Kellman and Spelke's (1983) experiments. Motion would not provide information for object unity, however, if the moving surfaces could be seen to be separated in space.

Does object perception begin with an analysis of surface motion or an analysis of bodily cohesion? The present experiments attempted to distinguish these possibilities by investigating infants' perception of objects that are separated by a gap that is directly visible. If object perception depends on a tendency to group together surfaces that move together, then two commonly moving surfaces should be perceived as a single unit, even if they are visibly separated. If object perception depends on a tendency to group surfaces into cohesive bodies, then two commonly moving surfaces should be perceived as distinct units if they are visibly separated.

In the present research, perception of object boundaries was studied in two ways. First, three experiments investigated patterns of reaching, at 5½ months of age, for objects that were visibly adjacent or visibly separated. In different conditions, the objects were stationary, they moved together, or they moved relative to each other. Second, one experiment investigated patterns of habituation and dishabituation of looking time, at 3½ months of age, to visibly adjacent or separated objects that underwent common or relative motion.

The Reaching Experiments

These experiments used the reaching method of Hofsten and Spelke (1985). Five- to 6-month-old infants were allowed to reach for two objects that were arranged vertically so that their adjacency or separateness was fully visible. The lower of the two objects was rather large in height and width but not in depth. The higher object was less tall and wide but it was thicker and thus it protruded in front of the lower object, its front surface closer to the infant (see Figures 1 and 2). As in Hofsten and Spelke's studies, all reaches to the upper object, to the lower object, and to both objects at once were separately recorded.

How can patterns of reaching shed light on infants' perception of the boundaries of these objects? Experiments have documented that 5- to 6-month-old infants who are presented with two distinct objects tend to reach only for one of them (Willats, 1985). If the objects appear at different distances, such infants tend to reach for the closer object (see Yonas & Granrud, 1985, for a review). If infants perceived the two objects in the present displays as distinct, therefore, they were expected to reach primarily for the higher and smaller object, because it was considerably closer to them.

Experiments have also documented that infants who are presented with a single object tend to reach for it by grasping its external borders (Bower, Dunkeld, & Wishart, 1979; Spelke & Hofsten, 1986). If infants perceived the two objects in the present displays as a single unit, therefore, they were expected to reach anywhere on the external borders of the two-object display. Most of these reaches should result in contact with the lower and larger object, because it constituted most of the external borders of the two-object display owing to its greater height and width. Some of these reaches might also result in contact with both objects: If an infant reached for the two-object display as a single unit, his or her hand would contact both objects at once whenever it was directed to a part of the border of the two-object display that both objects shared.

Accordingly, the principal measure in these studies, as in Hofsten and Spelke's studies, was the proportion of reaches that terminated in contact with the smaller, closer object as compared with reaches that terminated in contact with the larger, more distant object or with both objects at once. A second measure simply considered the absolute frequencies of reaching to the closer object under different stimulus conditions. Scores on both measures should be higher for displays in which infants perceive the two objects as distinct units.

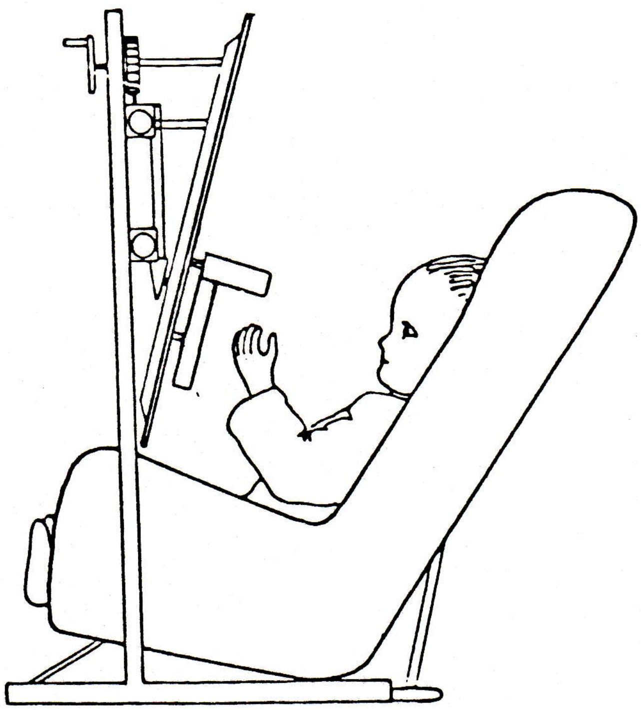

Figure 1. Side view of the apparatus with a display of adjacent objects.

The first experiment investigated infants' reaching for the adjacent and the separated objects when the objects were stationary. In accord with the findings reviewed above, these spatial arrangements were expected to influence infants' perception of object boundaries. Thus, infants were expected to reach more for the smaller, closer object when the objects were separated than when the objects were adjacent. The second experiment investigated the effects of common and relative motion on reaching for the adjacent objects. These motion patterns were also expected to influence infants' perception, as in previous research. Thus, infants were expected to reach more for the smaller, closer object when the objects underwent relative motion than when the objects moved together.

The third and critical experiment investigated the effects of common and relative motion on reaching for the visibly separated objects. If the common and relative motions of surfaces specify object boundaries regardless of the surfaces' spatial arrangement, then the motion patterns should have influenced object perception and object-directed reaching exactly as in the second experiment. In contrast, if common and relative motions provide information about the hidden connections and separations among surfaces, allowing infants to group surfaces into cohesive bodies, then the motion patterns should not have influenced infants' perception or reaching in the third experiment. Unlike the objects in Experiment 2 and in previous research, the objects in Experiment 3 could be seen to be separated in space and, thus, to form distinct cohesive bodies, however they moved.

General Method

Subjects

Forty-eight infants, 29 boys and 19 girls, served as subjects. The infants were 21 to 26 weeks of age, full-term, and resided in the Philadelphia area.

Displays and Apparatus

The displays and apparatus were the same as in Hofsten and Spelke (1985), except for the positions and dimensions of the objects. Each display consisted of one large background surface and two box-like objects, all covered with white contact paper with a random texture pattern of red and black dots. The 71 × 41 cm background surface was tilted toward the infant at an angle of 15° so that it was approximately perpendicular to the infant's line of sight. The objects were adjacent to and in front of this surface, one above the other. The height and width of the objects varied in different experimental conditions, but the upper object was always smaller than the lower object on both dimensions. The lower object measured 1.5 cm in depth, whereas the upper object measured 6 cm in depth and was 4.5 cm closer to the infant. The objects were either vertically adjacent or vertically separated by a 2-cm gap. They were positioned so that the center of the closer object in each display appeared roughly at the infant's eye level, at a distance of 11 cm. Figure 1 depicts the experimental apparatus with one of the displays of adjacent objects.

The background surface and the two objects either remained stationary or moved back and forth silently on a horizontal path. The motions were accomplished by means of two vertically stabilized carriages that moved along a set of horizontal steel bars. The background and the smaller, closer object were each permanently attached to separate carriages; the larger, more distant object could be attached to either carriage but could not move independently. When the two objects were attached to the same carriage, they moved together in one direction while the background moved in the opposite direction. When the more distant object and the background were attached to the same carriage, the two objects moved in opposite directions, and the background moved with the more distant object.[1] Altogether, the objects could move a maximum of 7 cm to the left or right. Even when they moved in opposite directions, the closer object remained above the more distant object at all times. The motion, which was slow and irregular, was produced manually by turning a handle at the back of the apparatus.

The experiment was recorded on videotape by one camera positioned above and to the left of the infant. This camera captured two orthogonal views of the infant's hands and arms: a direct view and a view reflected from a mirror placed to the infant's right so that it was slightly behind the infant and out of his or her view.

Design

Each experiment compared infants' reactions to two object displays during a series of eight trials. One display was presented on the first and last pair of trials, and the other display was presented on the middle four trials. The order of presentation of the two displays was counterbalanced across infants.

Procedure

During the experiment, the subject sat in a semireclining seat facing the experimental display. The seat was adjusted, and the infant was posi-

[1] Limitations on the apparatus prevented us from presenting displays in which the two objects moved both relative to each other and relative to the background. It is possible that the common motion of the more distant object and the background decreased the prominence of that object in the relative motion conditions. If that effect were the principal determinant of infants' object-directed reaching or looking, however, there would be no differences between reaching or looking patterns to the displays of adjacent compared with separated objects. The magnitude of these differences (see Experiments 3 and 4) suggests that the common versus relative motion of the more distant object and the background did not exert a major influence on infants' behavior in these studies.

tioned to maximize the comfort of the infant and the mobility of his or her arms. This was done informally; posture was not rigorously controlled. A parent stood behind the infant and was requested not to speak during the presentations. One experimenter operated the apparatus from a position behind it, where he could neither see nor be seen by the infant.[2] The other experimenter stood behind the infant, operated the video equipment, and timed the experiment.

Throughout the experiment, the object motion was adjusted to maximize the attractiveness of the display to the subjects. If an infant was inattentive to the display, as signaled by the second experimenter, the irregular character of the motion was enhanced by starting and stopping the motion a few times.

The experiment was divided into eight 30-s periods. At the end of each period, a hand was placed between the infant and the screen and any ongoing reach was interrupted. If the same display was to be presented again, the experimenter's hand was removed immediately, thereupon beginning the next trial. If a different display was to be presented, the infant's chair was withdrawn from the display, and the parent was asked to talk to the baby for 1 to 2 min while the display was changed. If the infant fussed, the experiment was interrupted, and the parent was asked to try to soothe her or him.

Dependent Measures

Each hand encounter with the smaller, closer object, with the larger, more distant object, and with both objects at once was scored from the videotape. A new encounter was scored whenever the subject began to touch or grasp an object and whenever the subject was already touching an object but lifted the hand(s) and changed the grip. No distinctions were made among reaches with the left hand, the right hand, or both hands at once. A two-handed reach was scored as one reach; if the two hands simultaneously contacted the two objects, the reach was scored as one reach to both objects. Two-handed reaches were relatively rare (5.6% of all reaches). No encounter was scored if the subject contacted an object with the back of the hand or if she or he swiped the arm and hand at the object without stopping it at any point. Two coders, working together, scored all subjects. The coders were unaware of the hypotheses of the present studies. To assess the reliability of their coding, a second pair of coders also scored 8 of the subjects. The two pairs of coders showed a moderately high agreement with regard to the number of scored reaches to each of the two objects in each condition ($r = 0.84$).

Because infants were studied at the age when reaching begins, some of them were not able to reach successfully. In order to limit the investigation to infants who could reach effectively, a subject was eliminated from the sample if he or she did not have at least one scorable reach during each trial. Three infants were eliminated for this reason. In addition, 17 subjects did not complete the study because of excessive fussiness, and 1 subject failed to complete the study because of an equipment failure. All these subjects were replaced.

Experiment 1

Infants were presented with two stationary objects that were adjacent, a closer object directly on top of a more distant object, and two stationary objects that were visibly separated, with the closer object suspended above the more distant object. Each subject was run in one of two conditions. In one condition, the two spatial arrangements (adjacent objects and separated objects) were created by varying the vertical position of the more distant object, leaving all other properties of the objects the same. In the other condition, the two spatial arrangements were created by varying the height of the closer object in such a way that both displays presented the same configuration of external borders. Patterns of reaching to these displays were observed.

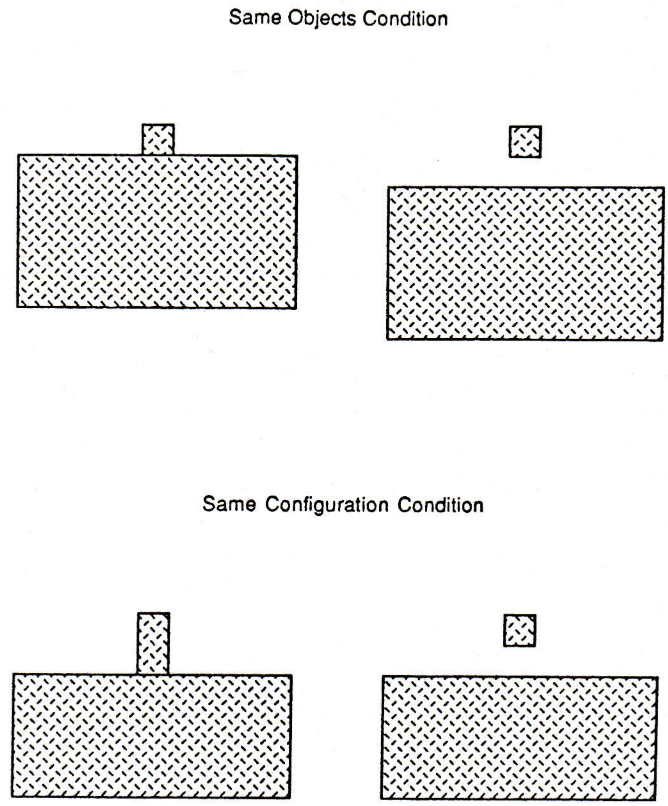

Figure 2. Front views of the object displays for Experiment 1.

Method

Sixteen infants, 11 boys and 5 girls, served as subjects. An additional 5 infants were rejected because of fussiness (4) or equipment failure (1). The displays are depicted in Figure 2. In one condition (same objects) the closer object measured 2 × 2 cm and the more distant object measured 18 × 10 cm. The more distant object was 2-cm lower in the separated display than it was in the adjacent display. In the other condition (same configuration), the closer object measured 2 × 4 cm in the adjacent display and 2 × 2 cm in the separated display, and the more distant object measured 18 × 8 cm. The outer contours of the two objects appeared in the same positions in both displays.

Results

Patterns of reaching are given in Table 1. The infants tended to reach more for the closer object when the objects were separated than when they were adjacent. The proportion of reaches

[2] This experimenter was aware of the displays that were presented on each trial, although he was not aware of the hypotheses of the experiments. By varying the rate of motion of the display, the experimenter was able to influence the infant's attention to each display; indeed, he was instructed to maximize the infant's attention. These variations in motion should not have affected the relative rates of reaching to different regions of a display.

Table 1
Experiment 1: Number of Encounters With the Top Object, the Bottom Object, and Both Objects Simultaneously for Each Subject and Condition

Subject	Adjacent objects			Separated objects		
	Top	Bottom	Both	Top	Bottom	Both
Same-object condition						
S.D.	7	9	17	10	8	6
B.M.	0	15	2	5	14	1
J.L.	10	5	7	12	9	8
C.A.	1	11	3	0	15	2
K.W.	6	17	2	7	12	9
M.S.	12	8	7	19	11	6
R.C.	2	5	10	4	15	4
J.S.	10	1	3	19	5	0
Same-configuration condition						
P.R.	9	9	6	17	9	2
T.W.	15	5	4	15	7	4
C.C.	2	11	3	2	6	0
E.M.	9	9	13	15	10	9
H.L.	12	10	12	17	6	0
J.H.	16	0	0	15	2	0
A.B.	2	11	4	4	9	3
P.D.	15	5	4	17	7	2

for the closer object, compared with reaches for the more distant object and for both objects at once, differed significantly across the two displays, Wilcoxon $T = 22$, $p < .01$. This difference was exhibited by 12 of the 16 subjects ($p < .05$, sign test)—6 of the 8 subjects in each condition. The absolute frequency of reaching to the closer object also differed reliably across the displays, Wilcoxon $T = 8$, $p < .001$. Twelve subjects reached more to the closer object when the objects were separated than when they were adjacent, whereas 2 subjects did the reverse ($p < .01$, sign test).

Discussion

The findings of this experiment agree with those obtained in a prior study of reaching for stationary objects arranged in depth (Hofsten & Spelke, 1985). As in that study, infants reached relatively more often for the smaller and closer of two objects when the objects were spatially separated than when they were adjacent. These reaching patterns provide evidence that infants perceived the separated objects as distinct units and the adjacent objects as a single unit. When objects are stationary, infants appear to perceive their boundaries by detecting the spatial adjacency or separation of their surfaces. This effect occurs both when objects are arranged in depth and when objects are arranged vertically.

One might question whether infants' reaching patterns were influenced by their perception of object boundaries and propose, instead, that reaching was affected by other properties of the displays. This possibility is unlikely, given the nature of the present displays. In the same-objects condition, identical objects appeared in the adjacent and separated displays, and only the height of the more distant object was varied. If the tendency to reach more for the closer object in the separated display were not due to the separation between the objects, it could only have been due to the absolute vertical position of the more distant object: Infants might have tended to reach preferentially for an object in the center of the display, a region occupied by the more distant object in the adjacent display but by no object in the separated display. If that were the case, however, the infants in the same-configuration condition should have reached more to the closer object in the adjacent display than in the separated display, because the closer object occupied the central region only when the objects were adjacent. In fact, the infants in the same-configuration condition did the opposite: They reached more to the closer object when it was smaller and failed to occupy the central region of the display than when it was larger and occupied that region.

Thus, reaching patterns appeared to be influenced primarily by the adjacency or separation of the objects. Infants appeared to reach for the two vertically adjacent objects as one unit and they appeared to reach for the closer of the two vertically separated objects as a distinct unit. In the next two experiments, these reaching patterns were used to investigate infants' perception of vertically arranged objects that moved together or separately.

Experiment 2

In Experiment 2, infants were presented with adjacent objects under conditions of common and relative motion. In the common-motion display, the two objects moved laterally together while the background moved in the opposite direction. In the relative-motion display, the smaller, closer object moved in one direction while the larger, more distant object and the background moved in the opposite direction. If these motion patterns influenced infant's perception of the objects' boundaries, so that the objects were perceived as one unit when they moved together and as two units when they moved separately, then infants should have reached more for the smaller, closer object in the relative-motion display than in the common-motion display.

Method

Sixteen infants, 8 boys and 8 girls, participated in the experiment. Seven additional infants were rejected because of fussiness (6) or failure to reach (1). Both displays consisted of the adjacent objects from the same-objects condition of Experiment 1, moving in a common direction or in opposite directions (see Figure 3).

Results

Patterns of reaching are presented in Table 2. The infants reached more for the smaller, closer object when the adjacent objects moved in opposite directions than when those objects moved together. The effect of motion on the proportion of reaching for the closer object, compared with reaches for the more distant object or for both objects, was significant, Wilcoxon $T = 16$, $p < .005$, and was shown by 14 of the 16 infants ($p < .01$, sign test). In addition, motion reliably affected the frequency of reaching for the smaller, closer object, Wilcoxon

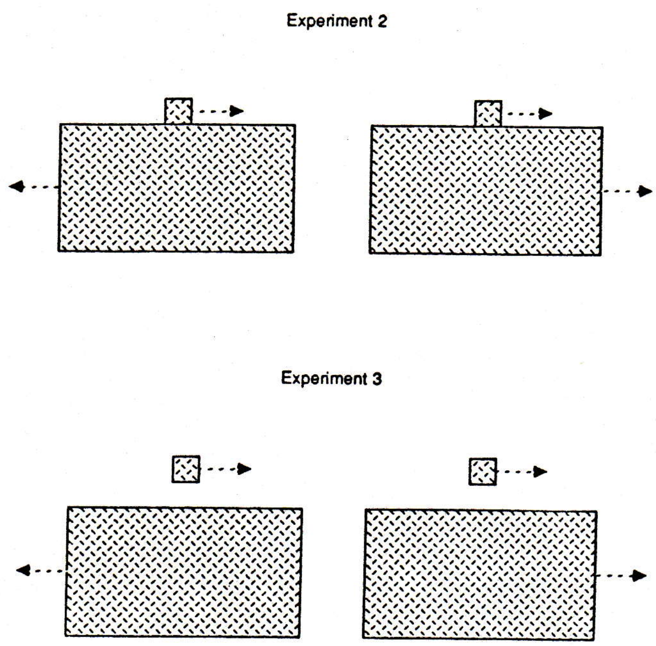

Figure 3. Front views of the object displays for Experiments 2 and 3. (Arrows indicate the direction and the extent of motion in the relative motion displays—left—and the common motion displays—right.)

T = 26.5, $p < .02$. Twelve subjects reached more for the closer object when the objects underwent relative motion than when the objects underwent common motion, and 3 subjects did the reverse ($p < .02$, sign test).

Discussion

The findings of this experiment agree closely with studies of the effect of motion on reaching for objects that are adjacent in depth (Hofsten & Spelke, 1985). Both the present and former studies provide evidence that infants perceive two adjacent objects as one unit when the objects move together and as distinct units when one object moves relative to the other. Motion influences perception of adjacent objects, whether the objects are adjacent in the vertical or in the depth dimension.

Experiment 3

Experiment 3 investigated the effects of motion on perception of objects that are visibly separated. Infants were allowed to reach for two vertically separated objects that moved either together or in opposite directions. If infants perceive objects by analyzing surface motions, irrespective of surface arrangements in space, then patterns of motion should have influenced reaching, as in Experiment 2. If infants perceive objects by grouping surfaces into units that are spatially cohesive, then patterns of motion should not have influenced reaching in this study.

Method

Participants were 16 infants, 10 boys and 6 girls. Nine other infants were eliminated because of fussiness (7) or failure to reach (2). Infants were presented with the separated objects from the same-objects condition of Experiment 1. The objects moved as in Experiment 2 (see Figure 3).

Results

As indicated in Table 3, infants tended to reach about equally to the two objects in both motion conditions. The proportion of reaching to the smaller, closer object, compared with reaches to the larger, more distant object and to both objects at once, was no higher when the objects moved together than when they moved in opposite directions, Wilcoxon $T = 39.5$, *ns.* Eleven subjects showed a higher proportion of reaching to the closer object under relative motion than under common motion, whereas 5 subjects showed the reverse pattern ($p > .10$, sign test). There was no tendency to reach for the closer object with a greater absolute frequency under relative motion than under common motion, Wilcoxon $T = 57.0$, *ns.* Nine subjects reached more to the closer object in the relative-motion condition, and 6 subjects did the reverse ($p > .10$, sign test).

A comparison of Experiments 2 and 3 revealed that the effect of motion on the frequency of reaching for the smaller, closer object was significantly greater in Experiment 2 than in Experiment 3, Mann–Whitney $U = 68$, $p < .025$. The motion patterns had a greater influence on infants' object-directed reaching when the objects were adjacent than when they were separated.

Discussion

When presented with two visibly separated objects, infants' patterns of reaching were unaffected by the objects' motion. Infants tended to reach about equally for the two objects, whether the objects moved in the same direction or in opposite directions. This negative finding contrasts with the findings of Experiment 2, in which the same motion patterns were presented with visibly adjacent objects. The finding also contrasts with the

Table 2
Experiment 2: Number of Encounters With the Top Object, the Bottom Object, and Both Objects Simultaneously for Each Subject and Condition

	Adjacent objects/common motion			Adjacent objects/relative motion		
Subject	Top	Bottom	Both	Top	Bottom	Both
B.F.	0	19	0	7	14	0
T.W.	14	8	7	12	12	5
S.M.	10	11	0	13	7	1
C.B.	4	9	9	18	14	4
J.D.	10	6	1	10	2	2
C.C.	4	13	6	13	9	10
N.P.	16	11	1	13	4	3
K.B.	2	5	1	4	4	0
B.S.	4	8	25	11	2	6
C.H.	8	3	11	18	1	6
B.B.	8	8	5	10	3	8
M.S.	10	5	1	7	8	2
J.H.	0	8	9	1	7	4
E.S.	9	9	12	10	7	14
R.W.	0	6	9	1	7	10
J.V.	6	6	12	8	4	11

Table 3
Experiment 3: Number of Encounters with the Top Object, the Bottom Object, and Both Objects Simultaneously for Each Subject and Condition

	Separated objects/ common motion			Separated objects/ relative motion		
Subject	Top	Bottom	Both	Top	Bottom	Both
C.H.	3	4	7	6	4	3
M.K.	10	4	0	4	20	1
J.S.	5	16	4	1	6	0
R.M.	12	9	3	10	12	2
M.L.	16	1	9	21	2	2
S.G.	3	11	1	6	7	2
P.H.	3	9	5	4	8	3
J.P.	7	17	9	14	8	5
L.E.	11	3	0	8	0	0
R.R.	0	12	0	2	12	3
J.G.	8	7	14	11	4	13
B.R.	3	6	7	3	1	6
M.K.	5	8	5	16	9	5
E.Y.	6	10	10	3	9	8
M.R.	4	11	1	6	9	7
L.H.	12	5	1	8	2	7

findings of prior studies of reaching for moving objects that were separated in depth (Hofsten & Spelke, 1985). Patterns of motion influence infants' perception of separated objects that are arranged in depth so that the gap between them cannot be seen directly. In contrast, these motion patterns do not influence infants' perception of objects whose spatial separation is directly visible.

Given that the objects in Experiment 3 were spatially separated, one might have expected infants to show a higher absolute frequency of reaching for the closer object, under both motion conditions, than infants showed in Experiment 2. In fact, total reaches to the closer object were no higher in this experiment (231 reaches) than in Experiment 2 (261 reaches). Research by Hofsten & Spelke (1985) suggested, however, that comparisons of reaching frequencies across experiments are not reliable indicators of perception of object boundaries, because of high intersubject variability in reaching frequencies and reaching preferences. Although the relative frequencies with which a single infant reaches for an object in two different configurations have been affected consistently by spatial and kinetic factors, the absolute frequencies of reaching for any given object have varied widely across subjects (Hofsten & Spelke). Table 3 indicates that intersubject variability was also high in Experiment 3: The absolute frequency of reaching for the closer object ranged over subjects from the highest score in any response category of the experiment (21) to the lowest score (0). Our attempts to maximize each infant's comfort, at the expense of strict control over posture, may have contributed to the high intersubject variability in reaching patterns by increasing the variability in infants' positions relative to the display. Thus, Experiment 3 may have included, by chance, a high proportion of subjects whose posture induced them to reach more for the lower part of the display, and this tendency may have been neutralized but not reversed by the introduction of a spatial gap between the objects.

Turning from absolute to relative reaching preferences, however, the findings of Experiments 2 and 3 are clear. In Experiment 2, motion affected infants' patterns of reaching for the closer of two adjacent objects. In Experiment 3, the same motions had no effect on infants' patterns of reaching for the two visibly separated objects. Infants' perception of object boundaries appears to depend not only on the motions of surfaces but also on the presence or absence of a directly visible separation between surfaces.

The Preferential Looking Experiment

Object-directed reaching has certain limitations as an index of perception of object boundaries. In view of the relative paucity of studies of young infants' reaching for arrays of multiple objects, the interpretations of any individual reaching pattern might be questioned. It would be desirable, therefore, if some additional procedure could serve as an independent test of the interpretations of a reaching experiment. In addition, studies of object-directed reaching cannot be conducted with infants below 5 months, because younger infants do not reach for visible objects effectively. It would be desirable if a different method could serve to investigate younger infants' perception of adjacent and separated object displays. These considerations motivated Experiment 4, which used a habituation-of-looking-time method to investigate 3-month-old infants' perception of object boundaries.

Experiment 4 consisted of two conditions. The infants in the separated-objects habituation condition were presented first with the separated objects from Experiment 3, undergoing the same motions as in that experiment. The objects were presented on a series of trials, alternately undergoing common and relative motion, until the infants met a criterion of habituation. Then, the infants were presented with the adjacent objects from Experiment 2, undergoing common and relative motion on six alternating test trials. The infants in the adjacent-objects habituation condition of Experiment 4 were presented with these displays in reverse: They were habituated to the adjacent objects undergoing common and relative motion and were tested with the separated objects undergoing those motions. Looking time was recorded throughout the habituation and test sequence.

How can patterns of looking in this experiment shed light on infants' perception of object boundaries? A large number of studies provide evidence that habituation to a collection of visual displays will tend to generalize to new but similar displays, and that infants will dishabituate (i.e., look longer) if they are presented with displays that they perceive as markedly different from the habituation displays (see Bornstein, 1985, and Spelke, 1985b, for reviews). The findings of the reaching experiments, therefore, lead to the prediction that different patterns of dishabituation will be observed in the two conditions of Experiment 4.

Specifically, the infants who are habituated to the separated objects should tend to generalize habituation to the display of adjacent objects undergoing relative motion (because, by hypothesis, the objects in this display are perceived as the same two objects as those in both the separated-objects displays) and they should dishabituate to the adjacent-objects common-motion display (because, by hypothesis, that display is perceived as a single, new object of a new shape). In contrast, the infants who are habituated to the adjacent objects should show no differential dishabituation to the two separated-objects test displays, because both of those displays present the same array of two objects (by hypothesis, the same two objects that infants had perceived on half of the habituation trials).

A second prediction follows from the findings of the reaching studies. In a number of experiments, it has been reported that rate of habituation is affected by the homogeneity or heterogeneity of the displays presented on different habituation trials: Infants habituate more rapidly if they are presented with similar displays over successive trials than if they are presented with dissimilar displays (Bornstein, 1985). Accordingly, infants who are habituated to the two separated-objects displays should habituate more rapidly than those who are habituated to the two adjacent-objects displays (because, by hypothesis, the former infants perceive the same two objects throughout the habituation sequence, whereas the latter infants perceive two arrays of different objects over the habituation sequence).

Experiment 4

Method

Subjects. Participants were 32 full-term infants, 12 to 18 weeks of age, who resided in or near Ithaca, New York. There were 19 boys and 13 girls. An additional 9 infants were eliminated from the study because of fussiness (6) or equipment failure (3).

Displays and apparatus. The experimental apparatus and object displays were the same as in Experiments 2 and 3. The displays were illuminated by two vertical fluorescent bulbs to the left and right of the infant. The displays and the infant were surrounded by off-white curtains that blocked the infant's view of the rest of the room. A white, 38 × 33 cm screen was raised and lowered in front of the objects in a display to begin and end each trial. The infant sat in a semireclining seat that was at eye level with the center of the display and at a distance of 66 cm from the closer object. At the infant's point of observation, the adjacent-objects display subtended 15.3° by 10.3° and the separated-objects display subtended 15.3° by 12.0°.

The objects underwent motions of the same kind and the same extent as in Experiments 2 and 3. Unlike those experiments, the motions were regular and were not varied to enhance the infant's attention. The objects moved at the rate of 8 cm (6.9°) per second. They were moved by an experimenter who stood behind the display, out of view of the infant. Two observers, to the left and right of the display, watched the infant through peepholes in the curtain. They recorded looking time at the display continuously by pressing buttons connected to a microcomputer, which gave a faint auditory signal at the end of each habituation trial and at the end of the habituation sequence.

Design. Sixteen infants participated in each condition. All the infants were habituated to the objects in one of the two spatial arrangements and tested with the objects in the other spatial arrangement. During the habituation sequence, the objects underwent common versus relative motion on alternating pairs of trials; the order of these motions was counterbalanced across infants. During the test sequence, the objects underwent common versus relative motion on six singly alternating trials, in an orthogonally counterbalanced order.

Procedure. The infant was placed in the seat by the experimenter, the parent(s) were taken behind the infant and asked not to interfere with the experiment, and the experiment began. On each trial, the screen was raised to reveal an object display that began to move immediately and that moved steadily throughout the trial. The trial lasted as long as one previously designated observer (the "primary" observer) judged that the infant was looking at the display; it ended when the infant looked away for 2 s continuously after looking at the display for at least .5 s. A trial also ended if the infant looked for 120 s. At the end of the trial the screen was lowered, the apparatus was changed to produce the other motion, if necessary, and then the screen was raised to begin the next trial. The intertrial interval was approximately 2 s between trials presenting the same motion (i.e., after Trials 1, 3, 5, etc.) and 5 s between trials presenting different motions (i.e., after Trials 2, 4, 6, etc.). Trials continued until a habituation criterion was met or until 14 trials had been presented, whichever came first. The criterion was a 50% decline in looking time on three consecutive trials, relative to looking time on the first three consecutive trials on which looking time equaled or exceeded 12 s. Thus, each infant received between 6 and 14 habituation trials.

After the habituation sequence, the screen was lowered, the experimenter appeared in front of the display, and he or she talked to the baby gently while changing the spatial arrangement of the objects behind the screen (and out of the baby's view). This change took about 15 s. Then the experimenter disappeared behind the display, the screen was raised, and the first test trial began. The six test trials followed the same procedure as the habituation trials. Because the motion was changed after every trial, the intertrial interval was always 5 s.

The two observers coded looking time throughout the habituation and test trials in ignorance of the particular displays shown to infants on any given trial. Interobserver agreement (seconds of agreement ÷ seconds of agreement + disagreement) averaged .87. All data analyses were based on the recordings of the primary observer.

If the infant became fussy during the habituation sequence, the experiment was halted, the parent tried to soothe him or her, and the experiment was resumed if and when the infant became quiet. If the infant became fussy during the test, the experiment was terminated and the infant was replaced. Decisions to terminate the experiment were made by the primary observer, in ignorance of the infant's looking times at the different test displays.

Dependent measures, data analysis, and predictions. Total looking time per trial was recorded for each habituation trial and each test trial, and these looking times served as the basis for all the analyses. The principal analyses concerned looking time at the two test displays by infants in each of the experimental conditions. Test trial data for the two conditions were analyzed separately, because the displays presented in the two conditions were different. The test displays for each condition were the same as the habituation displays for the other condition, however. Consequently, looking preferences between the two habituation displays of each condition served as a measure of baseline preferences between the two test displays of the other condition. Because all subjects received at least two habituation trials with each motion display in counterbalanced order, and because not all subjects received a third trial with both displays, looking times during the first four habituation trials were used to assess baseline preferences between the displays. For each habituation condition, these times were compared with the test-trial looking times of the infants in the opposite condition.

We predicted that the infants who were habituated to the separated objects would show longer test trial looking at the adjacent objects undergoing common motion than at the adjacent objects undergoing relative motion and that this preference would exceed any baseline preference for the former display shown by the infants who were habituated to the adjacent-object displays. In contrast, we predicted that the infants who were habituated to the adjacent-objects displays would exhibit no test preference between the two separated-objects displays, beyond whatever baseline preferences were found for the infants who viewed the separated-object displays during the habituation sequence.

Further analyses attempted to assess the relative rates of habituation

Table 4
Median Looking Times to Adjacent-Objects Displays

Trial	Common motion	Relative motion
	After habituation to separated objects	
1	13.0	6.2
2	8.2	4.6
3	5.4	6.0
Total	26.5	16.5
	Baseline	
1	11.4	12.4
2	9.4	7.3
Total	22.8	25.6

in the two experimental conditions. Three measures of rate of habituation were taken: the number of trials to the habituation criterion, the percentage of decline in looking time from the first three trials to the last three trials of the habituation sequence, and the total looking time throughout the habituation sequence (see Bornstein, 1985; Pêcheux, 1981; Streri & Pêcheux, 1986). We predicted that the infants who were habituated to the displays of adjacent objects would take longer to habituate, by these measures, than the infants who were habituated to the displays of separated objects.

Looking times were found to be highly skewed throughout the experiment: The slowly, regularly moving objects appeared to have a hypnotic effect on some infants, who looked at the displays for the maximum duration of 120 s on a number of trials. Accordingly, looking times during the habituation and test trials were analyzed using nonparametric tests.

Results

Separated-objects habituation condition. Median looking times during the six test trials are given in the upper portion of Table 4. After habituating to the separated objects undergoing common and relative motion, infants looked longer at the adjacent objects moving together than at the adjacent objects moving independently. The preference for the common-motion display is significant by an analysis of differences in total looking times at the two displays over the six test trials, Wilcoxon $T = 32$, $p < .05$. Thirteen infants looked longer at the adjacent-objects test display with common motion, and 3 infants looked longer at the adjacent-objects display with relative motion ($p < .02$, binomial test).

Median looking times at these two displays during the first four habituation trials of the adjacent-objects habituation condition are given in the lower portion of Table 4. Infants showed no preference for either motion display during the habituation sequence, Wilcoxon $T = 54$, $p > .10$. Eight infants looked longer at the common-motion display, and 8 infants looked longer at the relative-motion display during the first four habituation trials. The looking preference for the adjacent-objects common-motion display was significantly greater for the infants who viewed the adjacent-objects displays after habituation to the separated objects than for the infants who viewed the adjacent-objects displays at the start of the habituation sequence, Mann–Whitney $U = 77$, $p < .05$.

Adjacent-objects habituation condition. Median looking times during the test trials are given in the upper portion of Table 5. After habituating to the adjacent objects undergoing common and relative motion, infants looked no longer at the separated-objects common-motion display than at the separated-objects relative-motion display, Wilcoxon $T = 43$, $p > .10$. Nine subjects looked longer at the test display with common motion, and 7 subjects looked longer at the test display with relative motion.

Median looking times at the two motion displays during the first four habituation trials of the separated-objects habituation condition are given in the lower portion of Table 5. Subjects appeared to look longer at the separated objects when they moved independently, but this difference was not significant, Wilcoxon $T = 45$, $p > .10$. Nine infants looked longer at the relative-motion display, and 7 infants looked longer at the common-motion display. The looking preference between the two separated-objects displays was no different for the infants who viewed those displays after habituation to the adjacent objects than for the infants who viewed the separated-objects displays initially, Mann–Whitney $U = 142$, $p > .10$.

Rate of habituation. Table 6 presents the principal characteristics of habituation for the infants in the two experimental conditions. The number of trials to the criterion of habituation did not differ across the two groups, Mann–Whitney $U = 116$, $p > .10$. Habituation occurred in the minimum number of trials (six) for 5 infants habituated to the adjacent objects and 6 infants habituated to the separated objects. Three infants presented with the adjacent objects and 1 infant presented with the separated objects never met the criterion of habituation. The amount of decline in looking time from the beginning to the end of the habituation sequence also did not differ across the two habituation conditions, Mann–Whitney $U = 151$, $p > .10$.

In contrast, total looking time was markedly higher for the infants habituated to the separated objects than for those habituated to the adjacent objects, Mann–Whitney $U = 68$, $p < .05$ (two-tailed). This difference appears to suggest that the infants in the separated-objects habituation condition habituated more slowly than those in the adjacent-objects habituation condition, but a comparison of looking times on the first three habituation trials (i.e., the trials used to establish the criterion of habituation) casts doubt on that interpretation. Looking times at the

Table 5
Median Looking Times to Separated-Objects Displays

Trial	Common motion	Relative motion
	After habituation to adjacent objects	
1	7.4	6.6
2	4.6	3.7
3	2.1	5.3
Total	14.1	15.6
	Baseline	
1	30.6	37.6
2	10.2	31.4
Total	34.2	69.9

Table 6
Principal Characteristics of Habituation to Adjacent and Separated Objects

Measure	Separated objects	Adjacent objects
Mdn no. of habituation trials	7	8
Mdn % decline in looking time	.60	.64
Mdn looking time on first 3 habituation trials	101.7	32.9
Mdn looking time on last 3 habituation trials	42.2	13.5
Mdn total looking time	189.2	98.0

separated objects were already higher than looking times at the adjacent objects on the first three trials, before looking time began to decline, Mann–Whitney $U = 76, p < .10$ (two-tailed).

Discussion

After habituating to displays of two spatially separated objects alternately undergoing common and relative motion, infants dishabituated to a display of two adjacent objects undergoing common motion compared with a display of two adjacent objects undergoing relative motion. After habituating to displays of two adjacent objects alternately undergoing common and relative motion, infants showed no differential dishabituation to displays of two separated objects undergoing common and relative motion.

A number of potential explanations for the test preference in the separated-objects habituation condition may be ruled out, owing to the design of the experiment and the nature of the findings obtained. First, the test preference for the adjacent-object common-motion display cannot be explained as dishabituation to the common motion itself, because both the common and the relative motions had been presented equally often during the habituation sequence and the infants did not look at them differentially at that time. Second, the test preference cannot be explained as dishabituation to the objects' new spatial arrangement, because both the common- and the relative-motion test displays presented the same spatial arrangement of adjacent objects. Third, the test preference is not an artifact of a baseline preference for the adjacent-objects common-motion test display: Infants in the other experimental condition, who viewed the same two adjacent-objects displays with no prior habituation sequence, showed no looking preference between them. Finally, the test preference does not reflect the slow emergence of a general preference for common motion after prolonged viewing of common-motion and relative-motion displays, because this preference was observed only in the group of subjects that was habituated to the separated objects and tested with the adjacent objects, not in the group of subjects that was habituated to the adjacent objects and tested with the separated objects.

It appears, therefore, that infants looked longer at the commonly moving adjacent objects because they organized that display into different units from the displays presented during habituation. Infants perceived the objects in the two separated-objects displays and in the adjacent-objects relative-motion display as the same two distinct units, whereas they perceived the objects in the adjacent-objects common-motion display as a single unit of a different size and shape.

Thus, Experiment 4 joins Experiments 2 and 3 in providing evidence that infants perceive object boundaries by grouping surfaces into units that are spatially connected and that move as wholes. Experiment 4 bolsters the present interpretation of the studies of object-directed reaching, because it arrives at the same conclusions as those studies through the use of a different and independent experimental method. It also goes beyond the findings of the reaching experiments, because it provides evidence that capacities for object perception are present before infants begin to reach for objects effectively—at 3½ months of age.

The findings of Experiment 4 did not confirm one of our predictions: Rate of habituation was no faster for the infants who were habituated to the separated objects than for the infants who were habituated to the adjacent objects. In retrospect, however, two aspects of the data from this experiment cast doubt on our attempts to measure habituation rate. First, looking times throughout the experiment, and especially during the habituation trials, were highly skewed. Six infants (5 in the separated-objects habituation condition) looked at a display for the maximum 120-s trial duration on at least one habituation trial—a rare occurrence in most habituation studies. According to the intuitive impressions of the observers, these long looks did not appear to reflect active attention to the displays. Instead, some infants appeared to be mesmerized by the objects' motions: They stared at a display without actively scanning it or tracking the motion, in an apparently drowsy state. Therefore, total looking at the present habituation displays may be a poor index of active processing time and, thus, a poor index of habituation rate (Lécuyer, 1988; Pêcheux, 1981). Second, looking times were higher at the beginning of the habituation sequence for the infants who viewed the separated objects than for those who viewed the adjacent objects. When infants' initial looking times to two sets of displays are different, comparisons of total looking time or of other habituation parameters may not be meaningful indexes of relative rates of habituation to those displays.

General Discussion

The present experiments, in conjunction with those of Hofsten and Spelke (1985), shed light on the nature of the interaction between spatial and kinetic information as specifiers of object boundaries. When surfaces are arranged in depth, kinetic information overpowers spatial information for object boundaries: Two adjacent objects are perceived as distinct if they move separately, and two separated objects are perceived as one unit if they move together. When objects are arranged so that their adjacency or separation is fully visible, however, kinetic and spatial information interact in a more complex way. Adjacent objects are perceived as distinct units if they move independently, but visibly separated objects continue to be perceived as distinct units even if they move together.

The present findings could be explained in at least two ways. One explanation appeals to purely visual mechanisms: Object perception could depend on an analysis of continuous regions of retinal flow. In this view, surfaces would be grouped together if (a) they were arranged so that they projected images to adjacent regions of the retina and (b) they moved so that those regions underwent a common retinal displacement. This mechanism would seem to account for the present findings, because adjacent retinal images are projected by vertically adjacent objects or by any objects that are arranged in depth, but not by vertically separated objects.

An explanation of this type faces certain difficulties. First, any analysis of retinal motions must take into account the fact that surfaces project images with different retinal velocities when they move together at different distances from the observer. Because common motion has been found to unite surfaces that are arranged in depth (Hofsten & Spelke, 1985), the flow-detecting mechanism must take account of surface distance and its effect on retinal velocity. Second, research on infants' perception of surfaces that move together behind a common occluder indicates that commonly moving surfaces need not project adjacent images to the retina to be perceived as one unit (Kellman & Spelke, 1983). Regions of motion may be separated at the eye, if the surfaces that produce them stand partly hidden behind a common occluder. Third, studies of perception of partly occluded objects have shown that the necessary condition for perceived object unity from motion is not a common subject-relative displacement, but rather a common object-relative displacement (Kellman et al., 1987). Objectively moving surfaces are perceived by infants to lie on a single object, even if their displacement in the visual field is completely canceled by observer movement. Therefore, the perceived unity of moving surfaces cannot be based on detection of a simple retinal corollary to surface motion. Any unity-forming rule that is stated in retinal terms would have to be quite complicated (see also Marr, 1982).

Studies of haptic exploration and haptic perception cast doubt on the view that object perception depends on a purely visual analysis, because motion patterns influence object perception in the same way in the haptic as in the visual modality. In one series of experiments (Streri & Spelke, 1988a), 4-month-old infants were allowed to explore two rings, one in each hand, that could either move together rigidly or move independently. Subsequent patterns of dishabituation to visual displays of connected or separated rings provided evidence that the independently movable rings were perceived as separate objects, whereas the rigidly movable rings were perceived as one connected object. As in the case of vision, moreover, perception of object boundaries was not affected by static gestalt properties of the haptic displays (Streri & Spelke, 1988b). These findings suggest that object perception depends on a process that occurs after the visual or haptic perception of surface arrangements and motions—a process that can operate on information from different perceptual systems.

What kind of process could this be? One possibility is that object perception depends on central mechanisms that function to provide young infants with an initial conception of the physical world. Specifically, infants may conceive of the world as composed of entities that are *bounded* and *cohesive:* distinct, connected units that move as wholes, independently of one another (Spelke, 1988). This notion could lead infants to group surfaces into units by analyzing their arrangements and motions. When infants see two surfaces moving independently, they might infer that the surfaces lie on distinct objects even if the surfaces touch visibly or in depth, for the pattern of independent motion could not have been produced by a single cohesive unit. When infants see two surfaces moving together, they might be predisposed to consider the surfaces as parts of a single unit, because distinct and separated objects tend not to act on one another at a distance. Thus, infants would perceive two surfaces as connected, somewhere out of view, if the surfaces moved together behind a common occluder or moved together while remaining separated in depth. When infants can see that two surfaces are spatially separated, however, that separation would indicate by itself that the surfaces do not form a single cohesive body. Patterns of motion, therefore, would not influence infants' perception of visibly separated objects.

If this account is correct, it has several implications. First, objects as entities do not emerge exclusively through perceptual processes but, rather, are abstracted through rules of knowledge. Infants apprehend the unity and boundaries of objects by virtue of cognitive mechanisms that analyze the hidden relationships among parts of the perceived surface layout (Spelke, 1988). The view that objects are not detected by early perceptual mechanisms might help to explain why infants fail to apprehend object boundaries by detecting gestalt relationships (Kellman & Spelke, 1983; Schmidt et al., 1986; Streri & Spelke, 1988b) or simple retinal invariants (Kellman et al., 1986; Kellman et al., 1987). It would orient the student of object perception away from phenomena of sensory organization and toward phenomena attendant on intuitive theories of the physical world (see, e.g., Gentner & Stevens, 1983).

A second implication of this account is that cognitive mechanisms are present and functional at an early age. Contrary to the thinking of Piaget (1952) and generations of empiricists (e.g., Berkeley, 1709/1910), young infants have conceptions about the physical world, and these conceptions function to bring order to experience before infants are able to act on the world in a coordinated manner. Although this claim is at odds with a wealth of research that uses object-directed tracking and search as indexes of the object concept (see Harris, 1983), it is consistent with some recent studies that use methods involving no search to assess infants' understanding of spatio-temporal properties of the physical world (e.g., Baillargeon, 1986, 1987; Baillargeon, Spelke, & Wasserman, 1985; Leslie, 1982; Macomber, Spelke, & Keil, 1988; Spelke & Kestenbaum, 1986). The beginnings of physical understanding may precede and guide the developing coordination of action rather than the reverse.

If young infants have an object concept, there would seem to be a strong continuity, through human development, in conceptions of the physical world. Adults, like infants, organize the world into entities with enduring internal unity and external boundaries (Hirsch, 1982; Spelke, 1985a). Although knowledge of the physical world clearly grows with development (e.g., Kaiser, Proffitt, & McCloskey, 1985; Piaget, 1974), and although this growth may be accompanied by some reorganization (e.g., Karmilloff-Smith & Inhelder, 1974, Smith, Carey, & Wiser, 1985), development may center on a core conception that does not change. This conception may reveal itself, in part, through the infant's capacity to organize surfaces into units that can be grasped and explored by active reaching.

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