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Object Perception and Object-Directed Reaching in Infancy

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Five-month-old infants were presented with a small object, a larger object, and a background surface arranged in depth so that all were within reaching distance. Patterns of reaching for this display were observed, while spatial and kinetic properties of the display were varied. When the infants reached for the display, they did not reach primarily for the surfaces that were nearer, smaller, or presented in motion. The infants reached, instead, for groups of surfaces that formed a unit that was spatially connected and/or that moved as a whole relative to its surroundings. Infants reached for the nearer of two objects as a distinct unit when the objects were separated in depth or when one object moved relative to the other. They reached for the two objects as a single unit when the objects were adjacent or when they moved together. The reaching patterns provided evidence that the infants organized each display into the kind of units that adults call objects: manipulable units with internal coherence and external boundaries. Infants, like adults, perceived objects by detecting both the spatial arrangements and the relative movements of surfaces in the three-dimensional layout.

In order to act with maximal efficiency, a child must be able to structure the perceived world into objects: manipulable units with internal coherence and external boundaries. Are infants able to do this at the time at which they first begin to reach for that which they see? One way to address this question is to study infants' patterns of reaching under different stimulus conditions. The way in which infants reach for and explore the world could give insight into their perception of the world, indicating whether they are structuring what they see into objects.

For adults, object perception is determined mainly by three factors. First, the spatial arrangement of surfaces in a scene influences the grouping of those surfaces into objects. Surfaces that are contiguous in space tend to be perceived as belonging to the same object, whereas surfaces that are separated by a gap tend to be perceived as belonging to distinct objects. Second, the gestalt configurational properties of a scene influence perceptual grouping. Surfaces tend to be perceived as belonging together, if they can be connected to form a unit with a regular shape, smooth edges, and a uniform color and texture; surfaces tend to be perceived as lying on distinct objects, if units with better gestalt properties are created by that partitioning (Koffka, 1935; Wertheimer, 1923/1958). Finally, patterns of motion play a crucial role in adults' object perception. Surfaces that move together are perceived as belonging to the same object, whereas surfaces that move independently are perceived as belonging to different objects (Johansson, 1950, 1978; Johansson, von Hofsten, & Jansson, 1980; Wertheimer, 1923/1958).

A variety of experiments have investigated the effects of these factors on young infants' perception of objects. The first reported observations were made by Piaget (1954). He observed that his son Laurent, then about 6 months old, would reach for a small object

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dangling in the air or perched on someone's fingertips. If the same object was placed on another bigger object such as a book or a pillow, however, Laurent failed to reach for it, and he tended instead to reach for the supporting object (see also Bresson & de Schonen, 1976–1977; Wishart, 1979). It appeared that Laurent perceived the boundaries of an object when it was spatially separated from other objects. When the object was adjacent to a second object, Laurent may have perceived the two objects as one unit.

Other experiments using habituation of looking time methods and surprise methods have provided further evidence that infants perceive object boundaries by detecting the three-dimensional spatial connections and separations among surfaces (Kestenbaum, Termine, & Spelke, 1984; Prather & Spelke, 1982; Spelke & Born, 1983; Spelke, Born, Mangelsdorf, Richter, & Termine, 1983; see Spelke, 1984, for a review). For example, one experiment used a habituation technique to investigate infants' perception of adjacent objects and objects that are separated in depth (Prather & Spelke, 1982). Previous research had found that infants can be habituated to the number of objects in a display. After habituation to displays of two objects, for example, infants subsequently show little attention to new displays containing two objects, and they look longer to displays containing three objects (Starkey, Spelke, & Gelman, 1980; Strauss & Curtis, 1981). Separate groups of infants, therefore, were habituated to displays containing one object or to displays containing two objects that were spatially separated in the frontal plane. After habituation, all the infants were presented with a display of two adjacent objects and a display of two objects that were separated only in depth. The infants who had been habituated to one object looked longer at the objects separated in depth than at the adjacent objects; the infants habituated to two objects showed the reverse preference. These patterns of dishabituation provided evidence that infants perceive two objects as distinct units when they are separated in depth and as a single unit when they are adjacent. The findings of other experiments supported the same conclusion (Kestenbaum et al., 1984; Spelke et al., 1984).

If young infants do not perceive the boundary between two adjacent objects of different sizes, shapes, colors, and textures, it would appear that they do not perceive objects in accord with the gestalt principles of similarity, good continuation, closure, and good form. Studies of perception of partly occluded objects have provided further evidence that infants do not perceive objects in accord with these principles (Kellman & Spelke, 1983; Schmidt & Spelke, 1984). Infants have been habituated to a stationary, three-dimensional object placed behind a block that occluded its center. In different experiments, the object was a rod, a triangle, a cube, or a sphere. After habituation, infants looked equally at a complete object and at an object with a gap where the occluder had been. Their patterns of dishabituation provided no evidence that the infants perceived any of the objects as continuing behind the occluder. In contrast to adults (Kellman & Spelke, 1983; Michotte, Thines, & Crabbe, 1964), infants do not perceive the complete shapes of partly hidden objects in accord with the gestalt principles of organization.

Finally, experiments have begun to investigate whether infants perceive objects by detecting the movements of surfaces. It is a common observation that young infants are attracted by motion (see Banks & Salapatek, 1983, and Gibson & Spelke, 1983, for reviews). By the time infants start to reach, moreover, they are able to perceive the motion of an object precisely enough to catch it even if it moves rapidly (Hofsten, 1980, 1983; Hofsten & Lindhagen, 1979). The effects of motion on infants' perception of object boundaries, however, are not fully understood.

Experiments using habituation methods have investigated whether 4-month-old infants perceive partly occluded surfaces as a single unit when the surfaces move together. Kellman and Spelke (1983) habituated infants to a center-occluded object that moved in a lateral translation behind its occluder, so that its center never came into view. The infants subsequently generalized habituation to the fully visible, connected object that adults perceive in this display, and they dishabituated to an otherwise comparable object with a gap where the occluder had been. This pattern of dishabituation provided evidence that the infants had perceived the moving ends of the partly hidden object as connected behind the occluder. The infants perceived a moving object as a unit whether or not its visible ends were similar and aligned. This finding, and the finding that infants did not perceive a regular object such as a sphere as a unit when it was presented without motion behind the occluder, provided evidence that infants perceived the unity of a moving object by analyzing the motion itself, not by analyzing the object's configurational properties.

Subsequent experiments investigated the effects of different types of motion on infants' perception of objects. Motion in depth was found to be as effective as motion in the frontal plane (Kellman & Spelke, 1984). Only motion of the distal object was effective, not a pattern of proximal motion caused by movement of the baby (Kellman, Gleitman, & Spelke, 1984). Finally, it was necessary that the object move both relative to the occluder and relative to the background: infants did not perceive the unity of an object that moved together with the occluder, and they did not perceive the unity of an object that remained stationary against a stationary background while the occluder moved (Kellman & Spelke, 1983). For a young infant, therefore, the visible surfaces of a partly occluded object are perceived as connected only if they move together relative to all the surrounding surfaces.

Will infants perceive surfaces as lying on distinct objects if the surfaces move independently? One suggestive observation was reported by Piaget (1954) as part of his investigations of patterns of reaching for adjacent objects. Piaget presented a matchbox to Laurent and then placed it on a book. As usual, Laurent ignored the matchbox and grasped the book. In the course of this action, however, the book was tilted and the matchbox began to slide over its surface. This movement led to a change in Laurent's behavior: he reached directly for the moving matchbox. It is possible that the independent motion of the matchbox and the book led Laurent to perceive the boundary between the objects.

Unfortunately, Piaget's observation is open to a variety of interpretations that subsequent research have not disentangled. Although Laurent's behavior changed when the matchbox began to move, it is not clear that this movement changed his perception of the object's boundaries. It is possible, for example, that the matchbox and the book were always perceived as a single object. Laurent might have reached for the matchbox when it moved because infants are attracted to moving surfaces; he might have reached for the book when both objects were stationary because infants are attracted to whatever surface is largest or closest to them.

These possibilities raise questions about the relation between object perception and object-directed reaching. Do infants reach for any highly discriminable and attractive part of their surroundings, or do they reach specifically for unitary, bounded objects? If infants reach for objects, which object will they reach for when several objects are present? How is reaching affected by the spatial arrangement and the pattern of movement of the objects? Experiments by Hofsten (1979) suggest that infants reach preferentially for moving over stationary objects, whereas experiments by Yonas and his colleagues provide evidence that infants reach preferentially for the nearer of two surfaces (Yonas & Granrud, 1984; see also Bower, 1972). The joint effects of distance and movement have not, however, been studied systematically.

The following experiments were undertaken to investigate the effects of spatial and kinetic information on infants' perception of and reaching for objects. In the experiments, the subjects were presented with two objects, one in front of the other. The closer object was smaller and was centered in front of the more distant one, so that both objects were within reach and were substantially within view. The two objects were either adjacent or separated in depth. In some conditions, the objects were stationary; in other conditions, they moved either together or independently. Patterns of reaching for the objects were observed. If infants perceived the objects as distinct, they were expected to reach for the closer object. If the infants instead perceived the two objects as one unit, they were expected to reach for that whole unit and grasp it by the edges of the larger and more distant object or by the edges of the larger and smaller object simultaneously.

General Method

Subjects

Sixty-five subjects between 20 and 23 weeks of age were tested in the different experiments. They were healthy and full term, and they resided in the Minneapolis area.

Apparatus

The infant sat in a semireclining car seat on a table. The experimental display rested on the table directly in front of the infant at a distance of approximately 15 cm from the infant's forehead (see Figure 1).

The display consisted of three parts: one large background surface and two objects. The 74 cm × 41 cm background surface was tilted toward the subject at an angle of 15°. Two boxlike objects stood in front of this surface, one in front of the other. The larger of these objects was adjacent to the background and measured 12 × 10 × 2.5 cm. The smaller object was placed in front of the larger object. Two different small objects were used in different conditions. One object measured 5 × 5 × 2.5 cm and was placed adjacent to the larger object. The other object measured 5 × 5 × 0.3 cm and was positioned 2.2 cm in front of the larger object. The two small objects, therefore, had front surfaces of the same size, the same distance from the larger object, and the same distance from the infant. One of these objects was adjacent to the larger object in depth, whereas the other object was not (Figure 2).

The three parts of the display could either move back and forth in a horizontal direction or could remain stationary. The motions were accomplished with the aid of two vertically stabilized carriages that could move along a set of horizontal steel bars. The background was permanently attached to one of the carriages, and the smaller object was attached to the other carriage. The intermediate, larger object could be attached either to the background surface or to the smaller object; it could not be moved by itself. When the larger object was attached to the smaller object, the two objects could be moved together or could remain stationary together independently of the background, which could either move or remain stationary. When the larger object was attached to the background, these two units could move or remain stationary together, independently of the small object. When the larger object was attached both to the smaller object and to the background, then the entire display could either move or rest as a unit. The motion was produced manually by turning a handle at the back of the apparatus (see Figure 1).

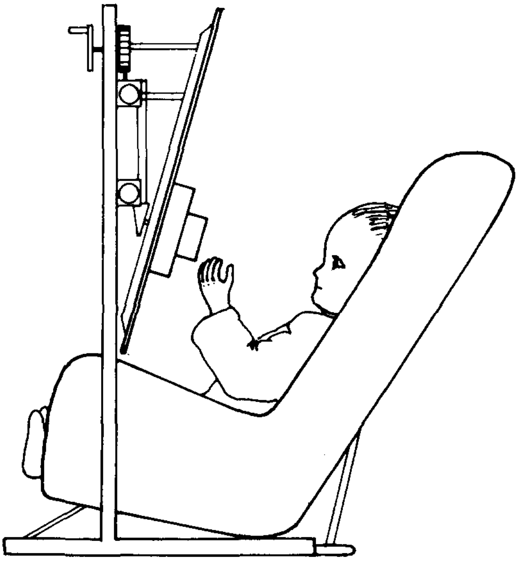

Figure 1. The experimental situation.

The smaller object was attached to its carriage via a 0.2 cm thick and 1.6 cm wide plastic bar going through a centrally placed, 5 cm horizontal slit in the intermediate object. This arrangement made it possible to move the smaller object 3.4 cm relative to the larger object, leaving a margin of 0.8 cm to the outer contour of the larger object at the two extreme relative positions. When the two objects moved or remained stationary together, the smaller object was always centered on the larger object leaving a 3.5 cm margin to the other contour of the larger object on both sides (Figure 3).

The background surface and the two objects were all colored in the same way. They had a base coat of white paint which was partly covered by a random texture pattern composed of red, yellow, blue, and green specks of various sizes. When the two objects moved relative to each other, texture elements of the more distant object were continuously covered and uncovered, as were parts of the slit through which the closer object was attached to the apparatus. When both objects moved relative to the background, texture elements of the background were continuously covered and uncovered. This is an important source of information for adults' perception of distinct surfaces (Gibson, Kaplan, Reynolds, & Wheeler, 1969). (Whenever the term *relative motion* is used in the present context, it refers to the composite visual event of relative motion plus accretion and delection of texture elements.)

The experiment was recorded on videotape by two cameras occupying orthogonal positions. One camera was located directly above the infant, and the other was located to the infant's left side. The two pictures were fed via a trixmixer into a video recorder.

Design

Each experiment compared infants' reactions to two object displays. Every infant in a particular experiment was presented with each of the two displays for four 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 infant sat in a semireclining infant seat facing the experimental display. The parent stood behind the infant and was requested not to speak to the infant during the presentations. One experimenter operated the apparatus from a position behind it, where he was not visible to the infant. The other experimenter stood behind the infant, operated the video equipment, and timed the experiment.

The manually produced motion was slow and somewhat irregular, in order to attract the attention of the subject. If the subject seemed uninterested in the display at some point, 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. The subject was first shown one of the two displays for two periods, the second display for four periods, and then the first display for two final periods. At the end of each period within a condition, a hand or a piece of cardboard was placed between the infant and the screen, and any ongoing reaching was interrupted. At the end of each condition, the chair was withdrawn from the display and the mother was asked to talk to the baby for 1 to 2 min before the next condition was presented to the infant. If the infant fussed, the experiment was interrupted and the mother was asked to try to soothe her or him.

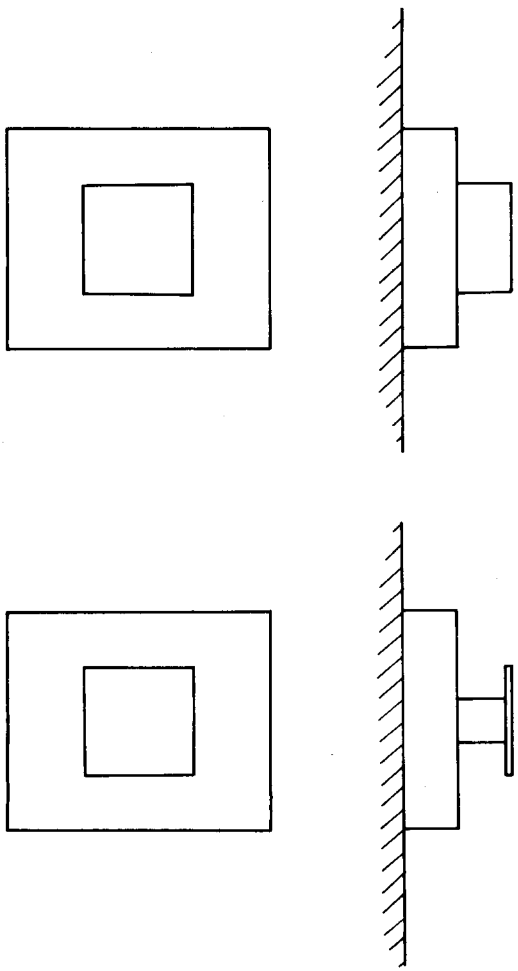

Figure 2. The two objects used in the experiments. (The upper figure shows the adjacent objects situation and the lower figure shows the separated objects situation.)

Scoring of Data

Not all reaches terminated in a grasp. Sometimes the infant just touched the object. It was assumed that touching an object was preparatory to grasping it. Therefore, each hand encounter with the small object, with the larger object, or with the background was scored from the videotape. A new encounter was scored whenever the subject began to touch or grasp an object, and also whenever the subject was already touching an object but lifted the hand and changed the grip. Sometimes the subject touched both objects at once as if trying to encompass them both in the grip. These encounters were coded in a separate category. No encounter was scored if the subject contacted an object with the back of the hand, or if he or she swiped the arm and hand at the object without stopping it at any point. One coder scored all subjects. To assess the reliability of his scoring, a second coder also scored 18 of the subjects, chosen at random. The two coders were compared with regard to the number of scored reaches to each of the two objects, in each condition, for each of the subjects in question. Their agreement was high, $r = 0.90$.

Although an effort was made to test infants who had just begun to reach, we did not wish to include infants who were not yet able to reach successfully. Some of the infants who were tested did not appear to be effective reachers. By our scoring categories, these infants either showed a very low rate of encounters with the objects (if they did not move their arms extensively), or they showed a high proportion of encounters with the background (if they moved their arms frequently but not in a coordinated manner). To eliminate these subjects, we adopted the following criteria. Subjects with less than 6 scorable encounters with any part of the display were not included in the study. This was true for 4 out of the 65 subjects tested. Subjects having 10% or more of their encounters directed to the background were also excluded. There were 9 such cases. Five of the remaining subjects failed to complete the experiment because of excessive fussing.

Data Analysis

The number of encounters with the smaller object, with the larger object, and with both objects was calculated for each infant and for each display. The tendency to reach differentially to the objects in the two different displays was assessed by a Wilcoxon matched-pairs signed-ranks test on the proportions of reaching for the smaller object. The consistency of the group effect across individual infants was assessed by a sign test.

In some cases, it would be of interest to compare the reaching performance of infants in different experiments. Unfortunately, comparisons across the present experiments are not possible because of wide intersubject variability both in the overall frequency of reaching and in reaching preferences between the two objects. Accordingly, conclusions will be based only on within-experiment comparisons.

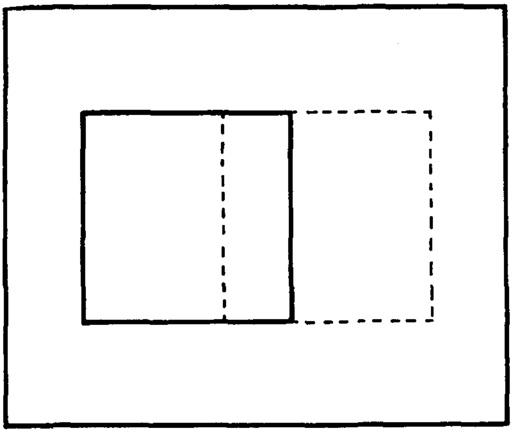

Figure 3. The extreme positions of the smaller object relative to the larger object in the relative motion condition.

Experiment 1

In Experiment 1, each infant was presented with the display of adjacent objects and the display of separated objects, both stationary. Reaching to each of the objects in the two displays was compared. If infants perceived the stationary adjacent objects as one unit, they were expected to reach for the edges of the larger, more distant object or for the edges of both objects simultaneously. If infants perceived the stationary objects separated in depth as two units, they were expected to reach for the smaller object.

Method

Eight subjects, 4 males and 4 females, participated in Experiment 1. Four additional subjects were rejected from the experiment because they failed to meet the criteria for effective reaching by having too many encounters with the background (2 subjects) or because they fussed (2 subjects). Four of the subjects in the final sample were presented first with the adjacent objects display, and the other 4 subjects were presented first with the separated objects display.

Results

The results of Experiment 1 are presented in Table 1. The subjects reached more for the smaller and closer object in the separated objects display, and they reached more for the larger and more distant object in the adjacent objects display ($p < 0.01$, Wilcoxon matched-pairs signed-ranks test). All 8 subjects showed a higher proportion of encounters with the smaller object when it was separated from the larger object than when it was adjacent to the larger object ($p < 0.01$, sign test). Table 1 also indicates that the incidence of encountering both objects at once was more than twice as high when the objects were adjacent than when they were separated. Seven subjects encountered both objects more frequently in the adjacent objects condition ($p < 0.05$, sign test).

Discussion

Experiment 1 provided further evidence that young infants perceive objects that are adjacent in depth as one unit, and that they perceive objects that are separated in depth as two units. The experiment also provided evidence that infants reach for the edges of a two-object configuration if they perceive the objects as one unit, and that they reach for the closer of two objects if they perceive the objects as distinct. Infants do not simply reach for the closest surface in a display; they reach for the boundaries of the closest perceived object. Reaching for displays of objects appears to be guided by an infant's perception of the objects' boundaries.

Experiment 2

How will a young infant perceive two adjacent objects that move relative to one

Table 1
Number of Encounters With the Closer, Smaller Object (01), With the Larger, More Distant Object (02), and With Both Objects Simultaneously for Each Subject and Condition of Experiment 1

	Objects adjacent			Objects spatially separated		
Subject	01	02	Both	01	02	Both
P.L.	4	17	5	6	9	2
S.N.	9	17	10	16	7	7
C.A.	30	21	3	49	24	7
N.A.	8	42	5	27	14	3
A.S.	20	29	2	22	19	0
J.B.	33	53	9	18	23	0
J.N.	20	22	4	17	12	0
L.Y.	20	18	7	12	11	1
Total	144	219	45	167	119	20

Note. The objects were always stationary.

another? Does the relative motion of two adjacent objects serve to break their perceived unity? To examine this question, a new group of infants was shown the display of adjacent objects under two conditions. Either both objects moved together, or the smaller object moved while the larger object was stationary.

Method

Eight subjects, 3 males and 5 females, participated in Experiment 2. Two additional infants were rejected because they failed to meet the reaching criteria. One subject reached too frequently to the background, and the other subject did not reach at all. The display of adjacent objects was used in all presentations. On four trials, the subjects saw the two objects move together against a stationary background. On the other four trials, the subjects saw the smaller object move in front of the stationary larger object and the stationary background.

Results

The results of Experiment 2 are shown in Table 2. The subjects tended to reach for the smaller object when it moved relative to the larger stationary object. When the objects moved together, the infants reached about equally for the two objects. The overall tendency to reach more frequently for the smaller object in the relative motion condition was significant ($p < 0.01$, Wilcoxon matched-pairs signed-ranks test), and it was found in a significant majority of the subjects (8 out of 8 subjects, $p < 0.01$, sign test). That is, each subject showed a higher proportion of encounters with the smaller object when it moved relative to the larger stationary object than when it moved together with the larger object. A greater number of encounters with both objects simultaneously occurred in the common motion condition, although only 6 of the 8 subjects showed this effect ($p < 0.10$, sign test).

When the two adjacent objects moved together, both the spatial arrangement and the pattern of motion should have led infants to reach for the larger object. In spite of this, two subjects (M.A. and S.H.) reached more for the small object. Were these subjects insensitive to the factors of adjacency and common motion? On the contrary: like the other subjects, these two subjects increased their reaching for the small object when the objects moved relative to each other. This finding suggests that the base preference between the large and small object varies considerably between subjects. What remains consistent, however, is the change in the reaching preference between conditions.

Table 2
Number of Encounters With the Closer, Smaller Object (01), With the Larger, More Distant Object (02), and With Both Objects Simultaneously for Each Subject and Condition of Experiment 2

	Objects moving together			Only smaller object moving		
Subject	01	02	Both	01	02	Both
K.E.	11	13	10	21	1	5
M.A.	26	22	3	44	25	2
B.R.	33	25	9	29	8	4
C.H.	19	19	7	24	24	0
K.A.	2	4	4	5	0	0
M.R.	19	27	7	24	18	6
S.H.	25	16	3	36	17	7
M.I.	14	25	2	58	28	7
Total	149	151	45	241	121	31

Note. The objects were always adjacent.

Discussion

The results of Experiment 2 suggested that the relative motion between the adjacent objects separated the objects perceptually, but these results are not conclusive. As with Piaget's observations, it is possible that the introduction of motion influenced infants' reaching directly without affecting their perception of object boundaries. The infants might have reached for the little object when it moved alone because its surfaces were the only surfaces in motion. The infants might have reached equally for the two objects when both moved together because the surfaces of each object underwent the same amount of motion. In both cases, infants might have perceived the two objects as a single unit. Experiment 3 was conducted to distinguish these possibilities.

Experiment 3

Experiment 3 investigated infants' patterns of reaching for the display of adjacent objects when that display was subjected to two new

Table 3
Number of Encounters With the Closer, Smaller Object (01), With the Larger, More Distant Object (02), and With Both Objects Simultaneously for Each Subject and Condition of Experiment 3

	Only background moving			Background and larger object moving		
Subject	01	02	Both	01	02	Both
C.H.	16	16	7	24	15	4
D.A.	12	16	7	23	14	9
G.R.	3	16	2	10	17	3
A.M.	7	6	0	18	8	1
L.A.	15	7	6	13	2	3
K.A.	12	31	7	24	14	4
A.S.	10	17	3	14	11	1
R.A.	9	15	1	22	19	1
Total	84	124	33	148	100	26

Note. The objects were always adjacent.

patterns of motion. In one condition, the two objects were stationary and the background moved. In the other condition, the smaller, nearer object was stationary while the larger object and the background moved together. If infants simply reach for surfaces that move, then the subjects should have reached more for the background when it moved and the objects were stationary. Further, they should have reached more for the larger object and the background when they both moved and the little object was stationary. If infants reach for perceived objects, and if a pattern of relative motion separates adjacent objects for an infant, then infants should perceive one object as an independent unit not only when it moves against a second object that is stationary but also when it is stationary against a second object that moves. Accordingly, the subjects in this experiment should have reached for the little object when it remained stationary in front of the moving larger object and background, and they should have reached for the larger object when the two objects remained stationary against the moving background.

Method

Eight subjects, two males and six females, participated in Experiment 3. Two additional subjects were rejected from the experiment for failure to meet the reaching criteria. One of them reached too often to the background, and the other reached less than six times during the experiment.

The display of adjacent objects was used in all presentations. On half the trials, the two objects were stationary while the background moved. On the other trials, the smaller object was stationary while the larger object and the background moved together.

Results

The results of Experiment 3 are shown in Table 3. The subjects reached more for the larger object when the two objects were stationary against a moving background, and they reached more for the smaller object when it was stationary against the moving larger object and background. The overall effect is significant ($p < 0.01$, Wilcoxon matched-pairs signed-ranks test), and it was exhibited by a significant majority of the infants (8 out of 8 subjects, $p < 0.01$). That is, each subject showed a higher proportion of encounters with the smaller object when it remained stationary in front of the larger moving object than when it was stationary together with the larger object. The frequency of encounters with both objects at once did not differ across the two conditions.

Discussion

Experiment 3 provided evidence that it is not the motion of a surface itself that attracts and directs infant reaching, but the information carried by moving surfaces about objects and their boundaries. Infants do not reach for surfaces that move, but for objects

Table 4
Number of Encounters With the Closer, Smaller Object (01), With the Larger, More Distant Object (02), and With Both Objects Simultaneously for Each Subject and Condition of Experiment 4

	Whole display stationary			Background and larger object moving		
Subject	01	02	Both	01	02	Both
N.I.	6	5	1	10	4	2
K.T.	10	8	1	16	0	0
A.M.	10	8	1	11	1	2
D.U.	14	24	0	12	12	2
M.T.	8	23	1	23	11	2
N.S.	9	18	0	25	1	2
R.B.	10	7	2	10	0	0
Total	67	93	6	107	29	10

Note. The objects were always adjacent.

whose boundaries are defined in part by motion.

Although similar reaching preferences were observed in Experiments 2 and 3, the rates of reaching were lower in Experiment 3. This difference may reflect a tendency of infants to reach more frequently for an object display when the objects themselves are in motion. The difference between the experiments is not reliable, however, and it may be attributable to random variation in the reaching rates of different infants.

Experiment 4

Does a pattern of relative motion serve to separate surfaces that are otherwise perceived as a single unit? The findings of Experiments 2 and 3 suggest that it does, but they are not fully conclusive. In both Experiments 2 and 3, the relative motion condition was compared with a common motion condition. If common motion acts to perceptually unite surfaces in the visual field (Kellman & Spelke, 1983), then the effects of relative motion in the previous experiments might have been entirely negative: infants might have perceived the independently moving objects as distinct only because of the absence of a unifying common motion. Experiment 1 speaks against this interpretation, because it provided evidence that adjacency is unifying in itself, in the absence of motion. It is possible, however, that adjacency by itself is less unifying than adjacency plus common motion. Accordingly, Experiment 4 compared infants' reaching for two adjacent objects moving relative to each other with their reaching for two adjacent objects that were stationary.

Method

The display of adjacent objects was used. The subjects saw the display with no motion and with the pattern of relative motion used in Experiment 3, in which the smaller object was stationary while the rest of the display moved. Seven infants, 3 males and 4 females, participated in the experiment. Three additional infants were tested but did not meet the reaching criteria. One of the infants reached less than six times altogether, and the other two infants reached too often for the background. Three infants were presented with the stationary condition first, and 4 were presented with the relative motion condition first.

Results

The results of Experiment 4 are shown in Table 4. The subjects reached more for the smaller object when the larger object moved relative to it, and they reached more for the larger object otherwise. This effect is significant over the complete experiment ($p < 0.02$, Wilcoxon matched-pairs signed-ranks test) and it is shown by a significant majority of the subjects: All 7 infants showed a higher proportion of encounters with the smaller object when the larger object moved relative to it ($p < 0.01$, sign test). There were few encounters with both objects at once, and the infants did not tend to reach more for both objects in the stationary condition ($p > 0.10$, sign test).

Discussion

Experiment 4, in conjunction with Experiments 2 and 3, provided evidence that young infants perceive two sets of surfaces moving relative to each other as belonging to two separate objects, even when the surfaces are adjacent. Furthermore, the experiment provided evidence that reaching is not directed toward moving surfaces in the visual field, but toward the nearest of the objects defined by relative motion.

The stationary display of adjacent objects was presented both to the infants in Experiment 4 and to the infants in Experiment 1. Although the infants in the two experiments exhibited the same reaching preference for the larger object, those in Experiment 4 showed lower overall rates of reaching. It is possible that the introduction of a moving comparison display in Experiment 4 decreased infants' rates of reaching to the stationary display. Alternatively, the difference between the two experiments may derive from random variation in the reaching rates of different infants.

Experiment 5

The preceding experiments have investigated the effects of motion on infants' perception of adjacent objects, but not the effects of motion on perception of spatially separated objects. Accordingly, Experiments 5 and 6 investigated how infants perceive two objects that are spatially separated in depth but that move together, asking whether the introduction of a common motion would perceptually unite the two objects.

Experiments with partly occluded objects, reviewed earlier, have provided evidence that young infants will perceive partly hidden surfaces as connected behind an occluder if the surfaces move together (Kellman & Spelke, 1983). This finding indicated that infants can use common motion to unite surfaces in the visual field, under some conditions. From these studies, however, it is not possible to predict the effect of common motion on perception of two sets of surfaces that are separated in depth. The Kellman and Spelke experiments used displays which give rise to no determinate perception of object boundaries in the absence of motion: infants do not perceive the visible ends of a stationary, partly hidden object either as one connected object or as two separate objects. In the present experiments, in contrast, infants appeared to perceive the spatially separated objects as two distinct units when they were stationary: the spatial gap itself served to separate the two sets of surfaces in Experiment 1. The effect of common motion on infants' perception of these objects was therefore tested in Experiment 5.

Method

Four male and 4 female infants participated in the experiment. Five additional infants were rejected from the experiment because they reached too often to the background (2 infants), they reached too little (1 infant), or they fussed (2 infants). The subjects were presented with the spatially separated object display from Experiment 1. For half the infants, this display underwent the two patterns of motion studied in Experiment 2. On four trials, the two objects moved together against a stationary background; on four trials, the smaller, closer object moved alone against an otherwise stationary display. For the remaining infants, the display of separated objects underwent the two patterns of motion studied in Experiment 3. On four trials, the two objects were stationary against a moving background; on four trials, the smaller, closer object was stationary against the larger object and the background, which moved together. The order of the movement trials was counterbalanced across infants.

Results

The results are given in Table 5. The infants tended to reach more for the smaller object when the two objects moved independently, regardless of which object moved. The infants reached approximately equally for the two objects when the objects moved together. This interaction is significant ($p < 0.01$, Wilcoxon matched-pairs signed-ranks test), and it was shown by a significant majority of the infants (8 out of 8 subjects, $p < 0.01$, sign test). Encounters with the two objects at once were about equally frequent in the two movement conditions.

Discussion

Experiment 5 provided evidence that the patterns of motion influenced the infants' perception of the objects that were separated in depth. Infants reached primarily for the smaller object when the objects moved relative to each other; the proportion of reaching for

Table 5
Number of Encounters With the Closer, Smaller Object (01), With the Larger, More Distant Object (02), and With Both Objects Simultaneously for Each Subject and Condition of Experiment 5

Subject	Common motion 01	Common motion 02	Common motion Both	Relative motion 01	Relative motion 02	Relative motion Both
N.N.[a]	1	7	2	13	6	5
C.R.[a]	20	10	7	30	4	11
D.N.[a]	2	11	2	17	17	0
J.C.[a]	41	19	9	41	13	5
K.T.[b]	23	29	5	26	15	5
J.S.[b]	15	15	5	30	13	7
S.H.[b]	4	4	0	6	1	1
J.H.[b]	11	13	4	14	15	4
Total	117	108	34	179	84	38

Note. The objects were always spatially separated. [a] The relative motion was produced by moving only the smaller object, and the common motion was produced by moving both objects together. [b] The relative motion was produced by moving the larger object and the background against the stationary smaller object, and the common motion was produced by moving only the background.

that object declined when the objects moved together.

A comparison of the results of Experiment 5 with those of Experiments 2 and 3 suggests that the spatial arrangement of surfaces did exert some effect on infants' perception of the objects. The infants in Experiments 2 and 3 tended to reach more for the larger object than for the smaller object when the objects moved together. In Experiment 5, in contrast, the infants reached slightly more for the smaller object in the common motion condition. This difference is not reliable, however, and it may stem entirely from random variation in the reaching preferences of individual infants in the two experiments.

Experiment 6

The results of Experiment 5 suggested that the introduction of common movement had a unifying effect on infants' perception of objects that are separated in depth. The results of Experiment 5 are not fully conclusive, however, because the common motion condition was compared with a relative motion condition. The effects of common motion might have been entirely negative: infants might have reached less for the little object only because of the absence of relative motion. The results of Experiment 1 provided evidence against such an interpretation, because a spatial gap in itself seemed to separate objects perceptually. Nevertheless, Experiment 6 was undertaken to assess the effects of common movement on perception of spatially separated objects more directly, by comparing reaching for two separated objects that stayed together against a moving background with reaching for a totally stationary display.

Method

Four males and 4 females served as subjects. Another 2 infants were rejected from the experiment because of excessive reaching to the background (1 subject) or fussing (1 subject).

The infants were presented with the spatially separated objects, as in the previous experiment. In different conditions, the objects were stationary against a stationary background, or stationary against a moving background. Although the objects themselves never moved, one display presented infants with common motion of the objects relative to the background, and the other did not.

Results

The results are given in Table 6. When the display was entirely stationary, the infants reached about equally for the two objects.

Table 6
Number of Encounters With the Closer, Smaller Object (01), With the Larger, More Distant Object (02), and With Both Objects Simultaneously for Each Subject and Condition of Experiment 6

Subject	Whole display stationary 01	Whole display stationary 02	Whole display stationary Both	Only background moving 01	Only background moving 02	Only background moving Both
M.T.[a]	10	14	2	11	32	19
K.R.[a]	19	25	0	9	23	5
S.R.[a]	15	22	0	16	26	4
K.S.[a]	26	16	1	12	27	0
L.U.[b]	4	18	2	8	15	0
E.M.[b]	7	0	0	17	1	0
B.N.[b]	14	10	3	3	10	2
P.T.[b]	38	36	2	14	60	0
Total	133	141	10	90	194	30

Note. The objects were always spatially separated. [a] The objects were presented against the moving background before they were presented in a stationary display. [b] The objects were presented in a stationary display before they were presented against the moving background.

When the background moved, in contrast, the infants reached more for the larger, more distant object. The tendency to reach more for the larger object when the objects underwent a common movement relative to the background was statistically reliable ($p < 0.05$, Wilcoxon matched-pairs signed-ranks test), and it was exhibited by a significant majority of the infants (7 out of 8 subjects, $p < 0.05$, sign test). Overall, there were more encounters with both objects at once during the common movement condition, but this effect was produced primarily by one subject. Only three of the 8 subjects reached more to both objects at once in the common motion condition ($p > 0.10$, sign test).

Discussion

Experiment 6 provided evidence that the common motion of the two objects served to unite them. The infants appeared to perceive the two spatially separated objects as a single unit when the objects underwent a common movement. In this situation, kinetic information influenced infants' perception of the boundaries of the spatially separated objects. Even though the objects were separated in depth, it appears that they were perceived as a single unit when they moved together relative to the background.

Curiously, patterns of reaching for the stationary display in this experiment differed from patterns of reaching for the same display in Experiment 1. Although the infants in Experiment 1 reached more for the closer object when the two objects were stationary and separated in depth, the infants in Experiment 6 did not. It is possible that the presentation of the separated objects staying together against a moving background influenced infants' perception of the stationary display. After seeing the stationary objects against a moving background, infants might have continued to perceive these objects as a single unit when the background was stationary. The findings of this experiment are consistent with this possibility. Of the 4 subjects who first saw the objects in the fully stationary display, 3 reached more to the smaller object; of the 4 subjects who first saw the objects against the moving background, 3 showed the opposite tendency (see Table 6). It is possible, however, that this difference reflected only the considerable variability in individual infants' reaching preferences.

General Discussion

The findings of these experiments support three conclusions: Infants perceive configurations of relative motion, infants perceive arrangements of objects by detecting this motion, and infants reach for the objects they perceive, coordinating their actions with their perceptions. We consider each of these conclusions in turn.

Infants' Perception of Motion and Change

The experiments provide evidence that change plays an important role in the organization of perception in infancy and that the critical changes are the relative motions of surfaces, not their absolute displacements. When two objects remain stationary against a moving background, as in Experiments 3 and 6, or when two objects move together, as in Experiment 2, the subjects treat the objects as one unit separated from the background. When one object is stationary against a moving display, as in Experiments 3 and 4, or when one object moves while the rest of the display is stationary, as in Experiment 2, the infants treat that object as a separate unit.

These findings suggest that infants perceive motion in accord with principles that are similar to those which govern adults' perception (Johansson, 1950, 1978; Wertheimer, 1923/1958). Like adults, infants do not appear to perceive the absolute motions of individual surfaces. On the contrary, the motion of a specific surface appears to be seen only in relation to the motion of the other surfaces in the visual field. Surfaces with equal motion form one perceived unit, and surfaces with distinct motions form separate units. Stationary surfaces in a motion field are not treated differently from moving surfaces, because it is patterns of differential motion that provide information for the visual system, both in infancy and in adulthood.

Infants' Perception of Objects

The experiments provide further evidence that infants are able to perceive objects as unitary and bounded. Infants perceive objects by detecting the three-dimensional spatial arrangements and the movements of surfaces in a scene. Surfaces are perceived as lying on the same object when they are touching and/or when they undergo a common movement relative to the movement of other surfaces in the scene. Surfaces are perceived as lying on distinct objects when they are separated in space and/or when they move relative to one another. The findings of these experiments are consistent with the findings of experiments using habituation methods and surprise methods (e.g., Kellman & Spelke, 1983; Spelke et al., 1984). Thus, experiments using diverse methods provide evidence that infants perceive objects by detecting the spatial arrangements of surfaces and the movements of surfaces, and not by detecting the gestalt properties of surfaces.

By comparing infants' reactions to stationary and moving objects, Experiments 4 and 6 of the present series provide preliminary information about the interaction of the effects of kinetic and spatial information on infants' perception of object boundaries. The infants in Experiment 4 showed a stronger tendency to reach for the closer of two adjacent objects when the rest of the display moved relative to that object than when the whole display was stationary. Thus infants appear to perceive two objects as distinct units when the objects touch but move relative to each other. The infants in Experiment 6 showed a stronger tendency to reach for the larger and more distant of two spatially separated objects when the objects stayed together in a moving field, than when the whole display was stationary. Thus, infants appear to perceive two objects as one unit when the objects are separated in depth but move together. In the present experiments, therefore, kinetic information appeared to exert a stronger effect on infants' perception of objects than did spatial information. It is possible, nevertheless, that spatial information continues to affect perception of objects that move. When two sets of surfaces move together, for example, infants may perceive a unitary object more clearly if the objects are adjacent than if they are separated in depth. This possibility has not been tested.

Why did kinetic information outweigh spatial information in the present studies? One possibility is that kinetic information is inherently a more powerful organizer of visual scenes. Perception of motion may contribute more strongly to an infant's perception of object boundaries than does perception of spatial relations. According to this hypothesis, perception of objects depends on a hierarchy of organizing principles, and motion principles stand at the top of this hierarchy.

A second possibility is that kinetic information leads to a change in perception of the spatial connections and separations among surfaces. When two stationary surfaces are separated in depth so that the connection or separation between them is not visible, infants may perceive the surfaces as fully separated. When the same surfaces move together, however, infants may perceive these surfaces as connected in some way in the place where they are hidden. According to this hypothesis, perception of objects might depend on conceptions of physical causality. Infants may have the notion that objects do not normally act on each other at a distance, and this notion may lead them to infer that jointly moving surfaces are connected in places where a connection is possible but no connection is seen.

These hypotheses cannot now be distinguished, because the present experiments focused only on infants' perception of surfaces that were separated in depth. The hypotheses could be distinguished by experiments that investigate infants' perception of surfaces that are separated by a visible gap. If kinetic information supercedes spatial information because of the preeminence of a common motion principle, then infants should perceive two visibly separated surfaces as a single unit when the surfaces move together. If kinetic information only leads infants to infer that surfaces are connected in places where that connection is occluded, then infants should perceive two surfaces as separate units when the gap between them can be seen, irrespective of their movements. Experiments that attempt to distinguish these possibilities are in progress.

Reaching for Objects in Infancy

The present experiments also support conclusions about young infants' reaching. Five-month-old infants do not appear to reach primarily for surfaces of a particular distance, surfaces of a particular size, or surfaces undergoing a particular pattern of movement. Rather, infants appear to reach for collections of surfaces that are perceived to be separately manipulable units. They reach for the boundaries of perceived objects.

The findings of these experiments do not imply that the color, size, motion, and distance of surfaces have no effect on infants' reaching. In the present experiments, for example, infants tended to reach for the nearer and smaller of two objects whenever the boundary between the objects was perceived. Other investigations might find that infants tend to reach for the more brightly colored of two objects, or for the object that moves more actively, other factors being equal. The primary goal of an infant's reach, however, is not a region of a given size or distance, a region of a given color, or a region in motion. The goal is a unit that is perceived to be separately moveable.

When and how do infants develop the tendency to reach for objects? This question cannot be answered fully, because the earliest, visually oriented arm movements of prereaching infants (Hofsten, 1982, 1984) have not been investigated in relation to the properties of objects. It is worth noting, however, that the present experiments focused on infants who had just begun to attain the motor skill of coordinated reaching and grasping. The parents of these subjects reported that they had been observing successful reaching by their infants for two weeks or less. This report was consistent with our own observation that most of the infants reached with little assurance or facility. The development of the tendency to reach for objects does not, therefore, depend on extensive reaching experience or on the acquisition of a high level of reaching skill.

Perception and Action

In conclusion, these experiments serve to illustrate a delicate interplay of perception and action in the development of the child. By 5 months, human infants are able to structure the visual world into the kinds of units that we, as human adults, call objects, and they are able to direct their manipulatory actions to those units. It will be interesting to investigate the development of these abilities, tracing both the capacities on which they depend and the conceptions to which they give rise.

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