22 Perceptual Knowledge of Objects in Infancy

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The visible world is furnished with objects. These may be large or small, rough or smooth, rigid or flexible, and moving or still. Objects are encountered in shapes of limitless variety, arranged on surfaces in infinitely many possible configurations. But as adults, we nearly always perceive each object as unitary, as separate from the surfaces around it, and as persisting over time. Our ability to do this is intriguing, for the boundaries of an object are rarely preserved, in any direct way, in the structure of light at the eye.

Consider the portrait in Fig. 1. Ingres' painting depicts a complex arrangement of adjacent, interlocking, and partly hidden surfaces. The artist did not indicate directly which of these surfaces lie on the same object. For example, he did not show us that Madame Devauçay's left index finger is connected through her ring to her hand, that the arm of her chair is attached, behind her cape, to its back, or even that her cape and chair are distinct. His portrait presents only small fragments of his subject and smaller fragments of her surroundings. Yet we perceive Madame Devauçay, her chair, her clothing, and her jewelry. We carve Ingres' array of pigments into objects, much as we do when we scan dynamic arrays of light from ordinary scenes.

Adults perceive the boundaries of objects in a number of ways. In some cases, we seek to divide visual arrays into the simplest possible units, in accordance with the Gestalt principles of organization (Koffka, 1935; Wertheimer, 1923). Madame Devauçay's shoulder may appear connected to her neck, for example, by virtue of the principles of similarity and good continuation. In other cases, we draw on our knowledge about particular sorts

FIG. 1 Madame Devauçay, by Jean Ingres. Courtesy of the Musée de Chantilly, France.

of objects or knowledge about properties of the physical world. Knowledge of hands and jewelry, for example, suggests that Madame Devauçay's diamonds are connected to the band of her ring and separate from her finger; knowledge of the effects of gravity may dictate that each strand of

her necklace continues behind her back. But the detailed nature of our ability to perceive objects, and its development, remain unknown.

Studies of young human infants may shed light on this ability and on the knowledge that underlies it. In this chapter, I discuss research on infants' perception of an object as distinct from the surfaces behind it, as separate from any surfaces that touch it, and as continuing behind any surfaces that partly hide it from view. The studies provide evidence that infants perceive the unity and boundaries of objects in a variety of configurations. They perceive objects in some, but not all, of the ways that adults do. The similarities and differences between infants and adults will suggest a general account of the development of object perception.

PERCEPTION OF SUSPENDED OBJECTS

When young infants scan a layout of surfaces, can they ever perceive objects as unitary and persisting? It is hard to imagine a perceptual world without stable units—a world in constant flux. Yet many philosophers and psychologists have proposed that the infant's perceptions begin in such a state. This proposal is extremely difficult to refute, even after decades of experiments. But there is growing evidence that infants perceive the unity and boundaries of objects in the simplest of scenes: scenes in which one object is suspended fully within their view.

The best evidence is provided by studies of reaching (for example, White, Castle, & Held, 1964). At about 4½ months of age, infants begin to reach for suspended objects in visual scenes, and they adapt their reaching to certain spatial properties of the objects. They attempt to reach near objects more often than distant ones, they reach in the direction of an object, and they reach differently if an object is very large than if it is small. Infants even adjust their reaching to an object's pattern of movement. If an object moves at a constant rate into reaching distance, a 4- or 5-month-old infant will attempt to capture it. Careful observations show that the reaching is predictive. Infants aim toward a future position of the object, and they usually succeed in capturing it, despite their limited motor skill. They evidently perceive the object's movement and extrapolate its trajectory (von Hofsten, 1979, 1980; von Hofsten & Lindhagen, 1979). It certainly seems that these infants perceive suspended objects as separately moveable and persisting.

Observations of younger infants are more difficult to interpret. Within the first three months of life, an infant's arms and hands appear to be drawn to objects in the immediate surroundings (Twitchell, 1965). These movements rarely result in contact with an object, but they are adapted to some of an object's spatial properties such as its size (Bruner & Koslowski, 1972) and direction (Bower, Broughton, & Moore, 1970; von Hofsten, 1982a; de Schonen, 1977; Trevarthen, 1974; White et al., 1964). It is not clear, however, if these activities reflect the infant's perception of an object as unitary and bounded. Young infants could extend their arms toward the most interesting region of a visual array, without perceiving that region as a distinct object.

In view of these limitations, it is important to study the development of object perception with additional measures. Wendy Smith Born and I have begun a series of experiments using a surprise measure (Spelke & Born, 1982; Spelke, Born, Mangelsdorf, Richter, & Hrynick, in preparation). We have presented infants with a single object suspended in front of a background surface. Then we have moved the display in different ways, observing the infants' reactions to these movements. We ask whether infants expect, on some level, that an object can move independently of its background but must do so by moving as a whole.

In the first experiment (Spelke & Born, 1982), 3-month-old infants viewed an orange cylinder in front of a flat blue surface (Fig. 2). The object and background were carpeted and differed in texture as well as color. This display was stationary for 30 seconds and then a part of it began to move. In one condition, the object as a whole moved forward and back while the background remained still. In the other condition, the movement broke the object apart: Half the object moved forward in tandem with a neighboring region of the background (see Fig. 2). Infants viewed each of these events twice for 30 seconds at a time. Half the infants saw the stationary (S), object movement (O), and broken movement (B) episodes in the order S-O-S-B-S-O-S-B-S. The rest saw these episodes in the order S-B-S-O-S-B-S-O-S. Infants were videotaped throughout the session.

Born and I reasoned that if infants perceived the object as unitary and separate from the background, they would be surprised or puzzled when the object broke apart and moved together with part of the background. To assess surprise, we depended on the intuitive judgments of an experienced observer. The observer viewed the videotapes and judged whether each infant appeared more puzzled during episodes 2 and 6 or during episodes 4 and 8. Separate observers also recorded the duration of looking to the display during each episode, and they attempted to code the infant's facial expressions and motoric activity. None of the observers knew what event a baby was watching on any given trial.

The infants' apparent reactions of surprise were related significantly to these events. Most infants were judged to be more puzzled during the broken movement episodes than during the object movement episodes. According to the principal observer, the signs of surprise were subtle, they tended to vary from infant to infant, and they consisted more often of changes in motoric activity than of changes in visual attention or facial ex-

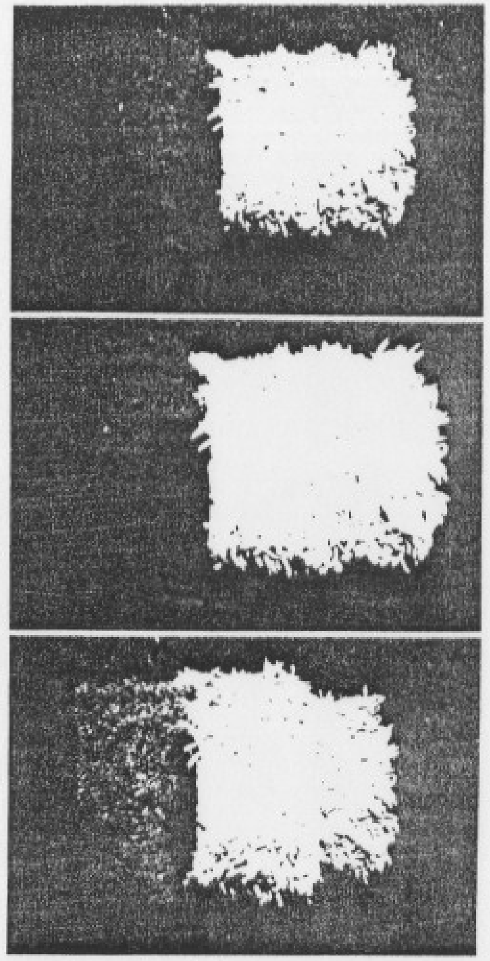

FIG. 2 Displays used by Spelke and Born (1982), Experiment 1.

pression. Analyses of the behavioral measures were consistent with these impressions. Infants looked equally long to the two kinds of events, with predominantly neutral expressions. Some infants appeared to stop moving abruptly or to breathe in a more pronounced manner during the broken movement episodes, but no single behavior reliably differentiated between the episodes. The observer's judgments suggested, nevertheless, that the infants perceived the object as unitary and bounded, and that they expected it to persist as a unit when it moved.

What information might infants use to perceive an object's boundaries? This object differed from its background in color and texture and was separated from it in depth. Two further experiments (Spelke & Born, 1982) investigated whether 3-month-old infants group together regions of an array by detecting the colors and textures of surfaces and/or by detecting the spatial arrangement of surfaces.

In the second experiment, the object and background were separated in depth but did not differ in color or texture. Infants were presented with the cylindrical object and the flat background surface, both covered with the orange carpeting. This display was moved as in the first study, infants were videotaped, and the same observer judged their reactions of surprise. The results were clear. A significant majority of the infants was judged to be more surprised during the broken movement events than during the object movement events. Infants apparently can perceive the boundaries of a suspended object by detecting its separation from the background.

In the third experiment, the "object" and "background" differed in color and texture but were not separated in depth. Infants viewed a flat surface consisting of two regions: a region that was similar in projective size and shape to the object in the first study, and a surrounding region that was similar in projective size and shape to the background. These regions were covered with the orange and blue carpeting respectively. The display was moved as in the first study: Either the orange region moved as a whole, or half of it moved with part of the blue region. The same observer judged reactions of surprise. In contrast to the previous experiments, there was no relationship between the observer's judgments and the movement episodes. In fact, slightly more than half the infants were judged to be more surprised by the unitary movement of the orange region than by the movement that broke up the orange and blue regions. The borders of these colored regions evidently were not perceived as the boundaries of an object.

Our studies suggest that infants perceive objects by detecting the spatial arrangement of surfaces in a scene. Young infants do not perceive objects by analyzing the colors and textures of those surfaces. Some observations of reaching support these suggestions. Newborn infants have been reported to extend their arms more often toward a three-dimensional object, separated in depth from its background, than toward a two-dimensional depiction of the object and background (Bower, 1972; Bower, Dunkeld, & Wishart, 1979; DiFranco, Muir, & Dodwell, 1978). This tendency is not observed in all studies (Field, 1976) or with all measures of reaching (DiFranco et al., 1978; Dodwell, Muir, & DiFranco, 1979). Its occurrence under certain conditions, however, may reflect the infant's perception that only the three-dimensional display contains a unitary, bounded object.

PERCEPTION OF PARTLY OCCLUDED OBJECTS

Most of the objects in a scene are not suspended in the air, fully in view. They lie beside or behind other things, forming a complicated arrangement of overlapping surfaces. An adult's perception of objects hardly suffers when things are partly hidden. In the still life in Fig. 3, for example, Chardin has arranged objects so that only one small apple can be seen without

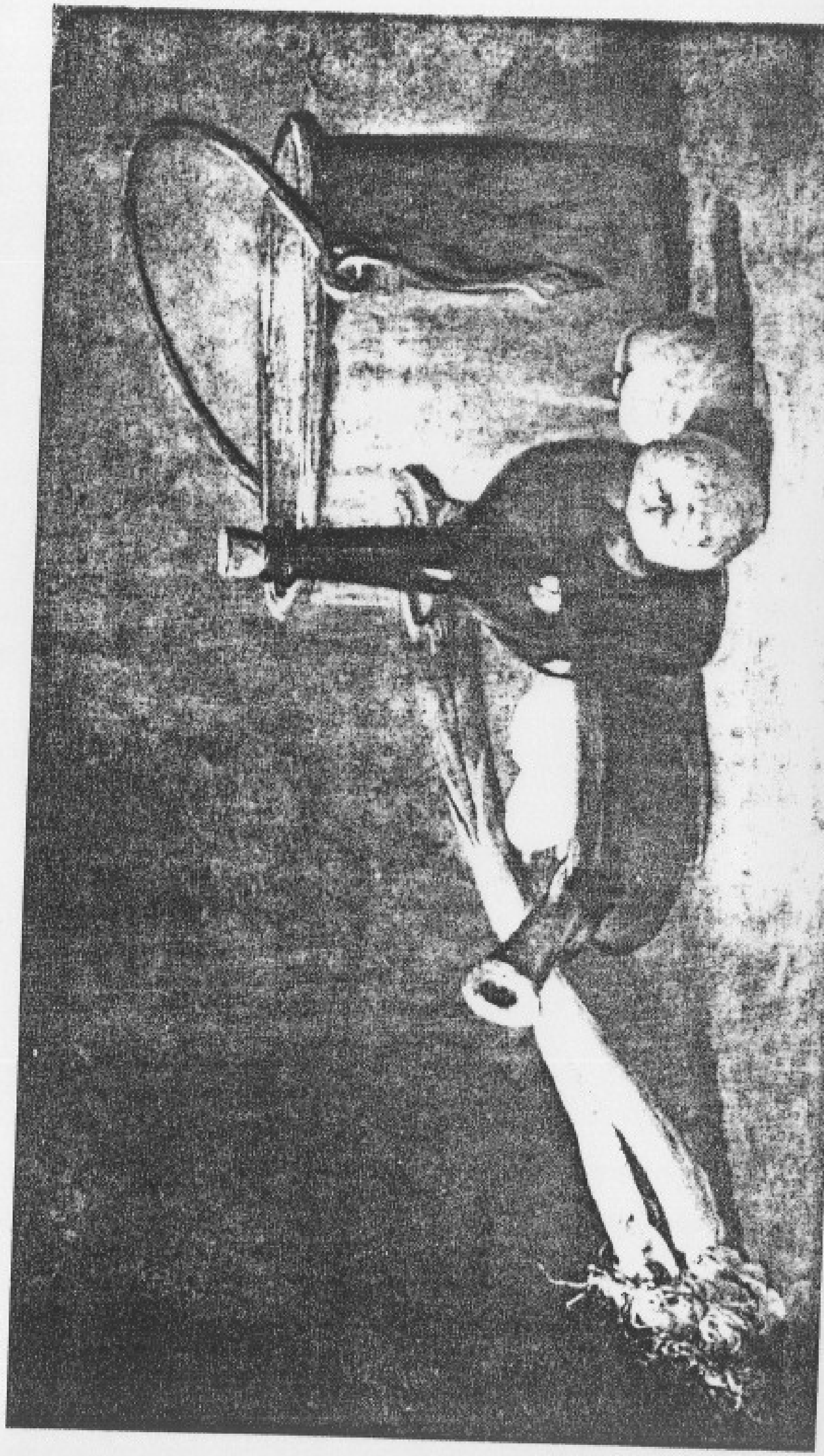

FIG. 3 La Ratisseuse (fragment), by Jean-Baptiste Chardin. From the Kaiser Friedrich Museum, Berlin.

obstructions. Nevertheless, we perceive leeks and eggs, a bottle and a cork, a mortar, a pestle, and more. The pot is seen as a single object with a regular shape, despite the apples that interrupt its base and the bottle that divides its visible surfaces in two. Each of the leeks looks unitary and distinct, although one partly hides the other and both appear in three separated areas on the canvas. In this still life, as in most real scenes, complete objects are perceived despite complex patterns of occlusion.

Do young infants perceive the complete shapes of partly hidden objects? An experiment by Bower (1967) suggests that they do. Following research on adults by Michotte, Thinès, & Crabbé (1964), Bower presented six-week-old infants with a wire triangle whose center was hidden by a cylinder. After the infants learned to suck in the presence of this display, he tested for generalization of sucking to four wire figures. One of these figures was a complete triangle; the others were triangles whose contours were interrupted in the region that had formerly been occluded. The infants sucked more frequently in the presence of the complete triangle, as if they had perceived the original triangle to continue behind its occluder in a definite way. Perception of the triangle could follow from the Gestalt principles of good continuation, closure, or good form. In separate experiments, Bower found no evidence that infants perceive two-dimensional patterns in accordance with these principles (Bower, 1965, 1966). Nevertheless, he suggested that infants perceived the three-dimensional display in accordance with the principle of good continuation.

Philip Kellman and I designed an experiment to test this suggestion (Kellman & Spelke, 1981). The principal display was a black rod placed behind a tan block that hid its center (Fig. 4). The two ends of this rod were of the same color and texture and were placed in alignment. According to the principles of good continuation and similarity, they should be perceived as parts of one object. Indeed, adults who were shown this display reported that they perceived a single, complete rod. Our experiment investigated whether 4-month-old infants would perceive this as well.

The study used a habituation of looking procedure. Infants in three groups were presented with different rod and block displays on repeated trials, until their looking time had declined to half its original level. The principal group was habituated to the partly occluded rod, one control group was habituated to a non-occluded complete rod, and one control group was habituated to a non-occluded rod with a gap in its center. The block stood behind the rod figures in the control conditions. After habituation, all the infants viewed two test displays: the complete rod and the rod with the gap, with no block present (see Fig. 4). We expected infants in the control groups to look longer to the rod display they had not seen. The critical question concerned the infants who had been habituated to the partly occluded rod. If they had perceived the rod to continue behind the block, then they should look more to the broken test rod. If they had perceived the rod to end where the block began, then they should look more to the complete test rod.

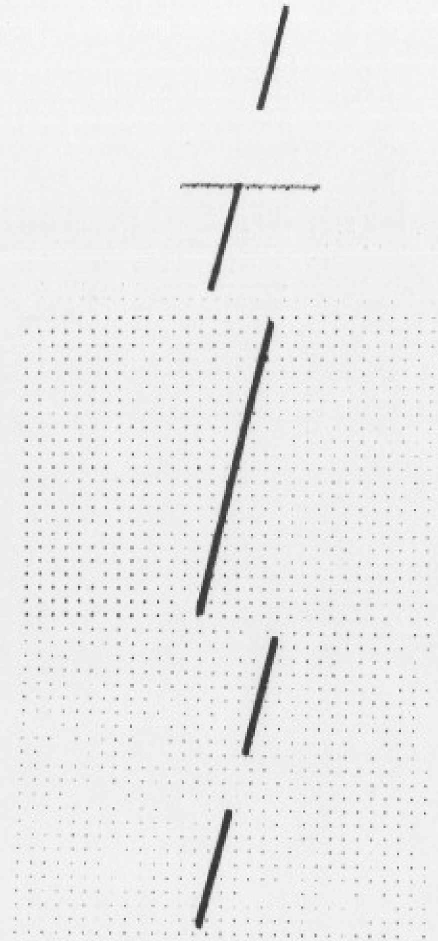

FIG. 4 Principal displays used by Kellman & Spelke (1981), Experiment 1.

The infants in the control groups looked markedly longer to whichever rod display was novel. But to our surprise, the infants in the experimental group looked equally to the two test displays. It appeared that they had perceived the partly occluded rod neither as two broken fragments nor as a single connected object.

Kellman and I wondered next whether these infants had seen the partly occluded rod at all: Might infants fail to attend to any object that is partly hidden? Accordingly, our second experiment investigated whether infants perceive the shapes of the visible surfaces of a partly hidden object.

The experiment consisted of two conditions. One group of 4-month-old infants was habituated to the partly occluded rod display used in the first study. A second group was habituated to a rod with a large gap in its center, standing behind the same block. The ends of the rod fragments could be seen above and below the block. After habituation, both groups were presented with the complete rod and the broken rod with the large gap. If infants perceive the visible areas of a partly occluded object, then those who had been habituated to the complete partly hidden rod should have dishabituated to the test rod with the large gap: This display could not have been present during habituation, for the gap was too large to have been covered by the block. For the same reason, infants who had been habituated to the rod with the large visible gap should have dishabituated to the complete test rod. Infants in both groups showed these patterns of dishabituation. Evidently, they had perceived the rod figures as well as the block in the occlusion displays.

These experiments suggest that 4-month-old infants perceive the visible areas of a partly occluded rod, but they do not perceive whether the rod continues behind its occluder. The rod had visible surfaces that were identical in color and texture and were placed in alignment. Infants do not appear to perceive objects by detecting these relationships.

Our next experiment investigated whether infants would perceive partly hidden objects in accordance with the principles of closure and good form. The principal display was patterned on those studied by Michotte and Bower. It consisted of three interconnected black rods in the shape of an equilateral triangle, with a tan block occluding its center. Adult subjects reported seeing a complete triangle behind the block, as had the subjects in Michotte's original studies. Perception of the unity of this triangle was rated as even more compelling than perception of the unity of the rod in the first experiment.

The experiment followed the method of our first study. Three groups of 4-month-old infants were observed. One group was habituated to the triangle partly hidden behind the block, and two control groups were habituated to complete and broken triangles in front of the block. After habituation, all the infants were tested with the complete and broken triangles with no block present. The patterns of dishabituation were the same as in the first experiment. Whereas infants in the control conditions looked longer to the test display they had not seen, infants in the principal condition looked equally to the two test displays. When presented with the partly hidden triangle, these infants evidently had not perceived it either to continue behind the block or to end where the block began. The experiment suggests that infants do not perceive the unity of a partly occluded object, even if its visible ends are similar, are aligned, and can be connected to form a simple, symmetrical figure. Although our finding differs from that of Bower (1967), this conclusion agrees with Bower's conclusions from his studies of perceptual organization of two-dimensional displays (Bower, 1965, 1966).

In our next experiments, we turned to the Gestalt principle of common fate. We investigated whether 4-month-old infants would perceive the unity of a partly hidden object when the object moved as a whole. The infants in this experiment were presented with a partly occluded rod, as in our first study, but now the rod was moved. It moved left and right repeatedly on a horizontal path, though never so far as to bring its center to view. Adults who viewed this display reported that they perceived a single connected object. Their impression of a unitary rod was as strong as their impression of a unitary triangle in the preceding study, and stronger than their impression of the unity of the original stationary rod.

After infants were habituated to the moving rod display, they viewed the complete rod and the rod with a small gap, moving in the same fashion on alternating trials. Subsidiary studies indicated that these displays were of equal intrinsic interest to infants. The subjects in this experiment, however, showed a marked preference for the broken test rod. Habituation to the moving, partly hidden rod generalized to the moving complete rod and not to the moving broken rod. It appeared that the infants had perceived the moving rod as a single unit that continued behind its occluder.

This experiment suggested that infants perceive the unity of a partly hidden object by detecting the movements of its surfaces. This suggestion is supported by the experiments by Bower (1965) on perceptual grouping of two-dimensional displays. Although infants did not group elements in these displays on the basis of their alignment or form, they did group together elements that moved together. Infants may perceive both objects and patterns in accordance with a principle of common fate.

We are beginning to investigate the types of movement that lead infants to perceive unitary objects (Kellman & Spelke, in preparation). In one study, translatory movement in depth was found to be as effective as translatory movement in the frontal plane. Infants who were habituated to a rod moving in depth showed marked dishabituation to a broken test rod. We believe that infants perceive objects by analyzing the movements of surfaces through three-dimensional space. A further study indicated that infants do not perceive the unity of certain rotating objects. Infants were habituated to a rod that rotated in the frontal plane about its midpoint. They subsequently looked equally to rotating complete and broken rods. Infants may perceive a partly hidden object only when its visible parts move so as to carry the object as a whole from one place to another.

In all these studies, infants were presented with a moving object whose surfaces were similar and aligned. A final experiment investigated whether infants would perceive two dissimilar, misaligned surfaces as connected if the surfaces moved in tandem. The principal display appears in Fig. 5. It consisted of a black rod that was partly visible above an occluding block and a red, speckled, irregular polygon that was partly visible below the block. The rod and polygon differed in color, texture, and shape, and neither their contours nor their major axes were aligned. These surfaces moved back and forth together behind the block, as in the first movement study.

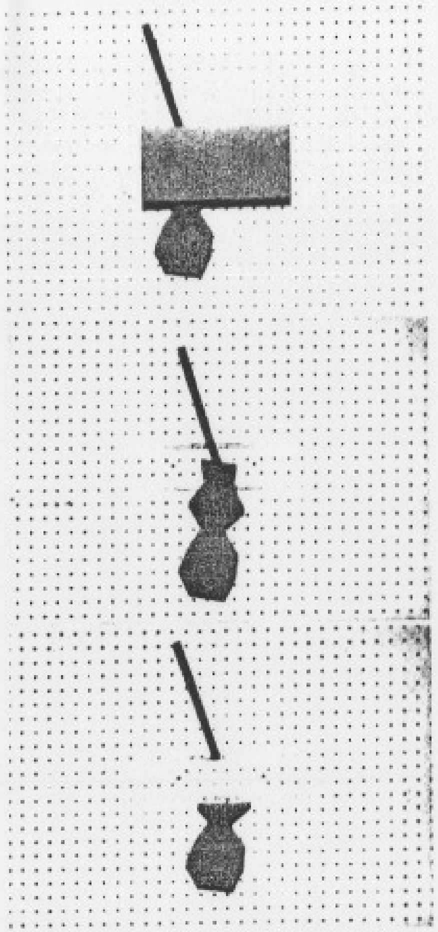

FIG. 5 Principal displays used by Kellman & Spelke (1981), Experiment 5.

When adults were presented with this display, many reported that the moving rod and polygon appeared connected behind the block. The impression that these surfaces were connected was less strong for this display, however, than for the display in which a single rod moved in the same manner.

Infants were habituated to this display and were tested with two fully visible, moving displays: a connected rod and polygon and a rod and polygon separated by a small gap (see Fig. 5). A subsidiary experiment indicated that these test displays were of roughly equal attractiveness to infants. Infants in the principal experiment, however, looked substantially longer to the test display with a gap. Dishabituation to the broken object was as pronounced in this study as in the study with the moving rod. Infants appear to perceive the partly hidden ends of an object as connected when they move together, whether or not their surfaces are similar and their edges are aligned.

In summary, infants can perceive objects by detecting the movements of surfaces through a scene. They perceive the unity of a partly hidden object

if its surfaces undergo a common translation, either laterally or in depth. Unlike adults, infants do not perceive the unity of a stationary partly hidden object, even if its edges are aligned, its surfaces are similar, and its shape is regular. In the language of Gestalt psychology, infants appear to follow the principle of common fate, but not the principles of good continuation, similarity, or good form. I am not suggesting that infants fail to detect these gestalt properties. There is evidence, in fact, that all these properties are detectable at an early age (see, for example, Bornstein, Ferdinandsen, & Gross, 1981; Schwartz & Day, 1979). Nevertheless, infants do not appear to use gestalt properties as information about the boundaries of a partly hidden object.

PERCEPTION OF ADJACENT OBJECTS

It is possible that young infants do not perceive the boundaries of any object, partly occluded or fully in view, by analyzing surface colors, textures, and shapes. In that case, infants would perceive certain scenes very differently than adults. Consider again the still life by Chardin (Fig. 3). As adults, we perceive each of the two leeks, two eggs, and two apples as separate from the other, despite the fact that they are touching. This tendency probably depends in part on our knowledge of these objects and in part on the principle of good continuation. The contour of one egg follows a different curve from the contour of the other, and these smooth curves are taken to mark each object's boundaries. We also see the leeks as separate from the adjoining pot and the apples as separate from the bottle. The principles of good continuation and similarity join forces to delineate these boundaries, since the separate objects differ in brightness and texture. If infants do not take account of the alignment and similarity of surfaces, they might not be able to perceive any two adjacent objects as distinct.

There have been no conclusive studies of infants' perception of adjacent objects, but a number of experiments suggest that two such objects are perceived as one. Piaget (1954) observed the efforts of one child to reach for objects that were supported in various ways. At 7 months, the child would reach for objects that were dangled in front of him, perched on an adult's finger tips, or placed on a large surface. Until the age of 9 to 10 months, however, he would not reach for any object that rested stably on a second object. Piaget suggested that two contiguous objects were seen as one unit by the child.

Piaget's most interesting observation suggested an exception to this rule. He placed a matchbox, toward which the child was reaching, upon a book. The child immediately ceased reaching for the matchbox, and his hand came to rest on the book. At this point, the book tilted and the matchbox began to slide over its surface. When the child saw this box in motion, he let go of the book and reached for it directly. Two adjacent objects may be perceived as separate if one moves relative to the other.

According to recent studies, most infants begin reaching for an object on a supporting object at a younger age than the child observed by Piaget. Nevertheless, the pattern of performance that Piaget describes has been substantiated: Young infants reach more readily for a stationary object when it is supported on the finger tips or on an extended surface than when it rests on another object. It has been suggested that the failure to reach for a supported object reflects the perception that the object and support are one unit (Bower, 1979; Wishart, 1979). Alternatively, it has been suggested that this failure reflects the immature control of prehension (Bresson, Maury, Pieraut-le Bonniec, & de Schonen, 1977; Bresson & de Schonen, 1976–1977). After a long series of pilot investigations (Born & Spelke, 1981), we have despaired of deciding between these possibilities with studies of reaching. Reaching and manipulation undergo large changes during infancy, and those developments may mask whatever perceptual changes are also taking place. Accordingly, we have begun to study perception of adjacent objects using two different methods. These experiments are at an early stage, and only tentative conclusions can be offered. They suggest, nevertheless, that infants in the first half-year perceive two adjacent objects as one unit.

One experiment relied on the surprise method already described (Spelke et al., in preparation). Infants were presented with two suspended objects: the large carpeted orange cylinder and a smaller painted yellow box. These objects appeared side by side, with one flat end of the cylinder flush against one side of the box. The display was moved in two ways: The cylinder moved forward alone, or the box and cylinder moved forward together. Infants were videotaped, and their reactions of puzzlement were judged by an observer. If the infants perceived the two objects as separate, they should not have been surprised when one moved independently of the other, and they might have been surprised when the two objects moved together. If the infants perceived the objects as connected, they should have been more surprised by the independent movement of the cylinder.

One group of 6-month-old infants participated in this experiment, and a separate group participated in a replication of the original object-background study using the display in Fig. 2. A significant majority of the infants in the replication study was judged to be more surprised by the movement of half the cylinder with the background than by the movement of the complete cylinder. Six-month-olds appeared as surprised as 3-month-olds when the cylinder broke apart. In the study with adjacent objects, most of the infants were judged more surprised by the movement of the cylinder than by the movement of the two objects in tandem. The observer's judgments were somewhat less consistent in this study, however, than in the previous experiments. It would appear that the infants perceived the adjacent box and cylinder as one unit. Nevertheless, two adjacent objects may not look quite as unitary, to a 6-month-old, as does one object of a single color and a simple shape.

The last experiment focused on perception of adjacent objects by 3-month-old infants (Prather & Spelke, 1982). The experiment made use of a phenomenon recently reported by Starkey (Starkey & Cooper, 1980; Starkey, Spelke, & Gelman, 1980) and by Strauss & Curtis (1980). Infants have been found to become habituated to the number of objects in a display, provided that the number is small. They respond to change and invariance in number irrespective of the particular objects being enumerated, their properties, and their spatial configuration. Prather and I accordingly attempted to habituate infants to displays containing either one or two objects. We hoped to discover whether infants perceive two adjacent objects as one thing or two.

Infants were presented with rectangular solid objects painted a uniform color and covered with glittering bits of paper of a contrasting color. Altogether we presented eight objects in four different colors, each of a different size and shape from all the others. Half the infants were habituated to displays containing one object. The other infants were habituated to displays containing two objects: On each trial, they saw two objects of the same color, with a clear spatial separation between them in the frontal plane. Over the course of the habituation trials, the infants in both groups were presented with six of the eight objects (three of the four colors) in a variety of spatial positions.

After their looking time had declined by half, infants were presented with two objects of the color they had not yet seen, occupying new spatial positions. There were four types of trials. On "one" trials, a single object appeared. On "two" trials, the two objects appeared, separated in the frontal plane. On "adjacent" trials, the two objects appeared side by side with no separation between them. Finally, on "occluded" trials, the two objects were separated in depth, one partly visible behind the other (see Fig. 6).

The results were suggestive. Patterns of looking on the "one" and "two" test trials indicated that most of the infants had not become habituated to the number of objects in the displays. But among the infants who did habituate to number, an interesting pattern of results was obtained. Most of the infants habituated to one object looked longer to the occluded than to the adjacent configuration, whereas most of those habituated to two objects showed the reverse preference. This interaction was significant. The infants appeared to treat the adjacent objects as "one" and the objects separated in depth as "two."

This experiment suggests that infants perceive two objects as distinct when they are separated in depth, even if their projections overlap at the eye. Infants perceive two objects as one unit, however, when they are placed side by side. Studies of adjacent objects give further evidence that infants

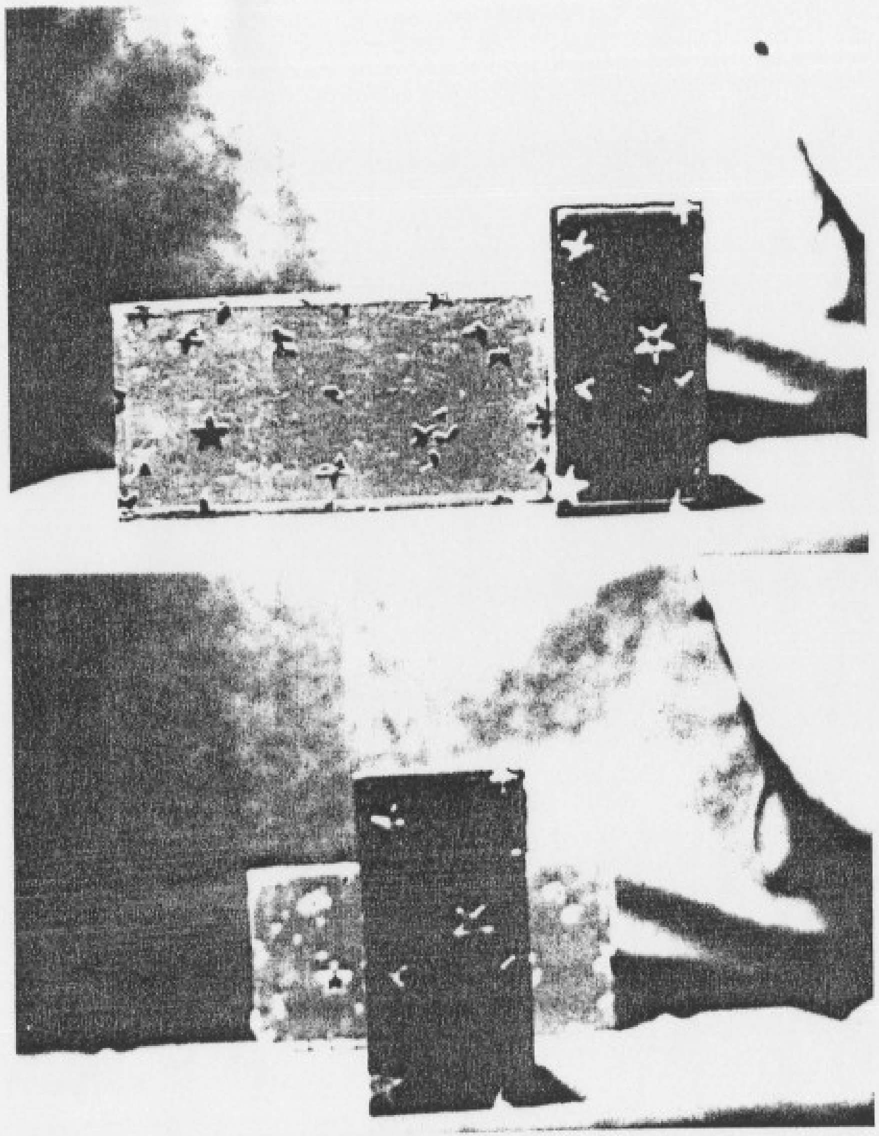

FIG. 6 Adjacent and occluded test displays used by Prather & Spelke (1982).

perceive object boundaries by detecting the spatial separations of surfaces and not by analyzing the alignment of surfaces or the shapes of the configurations those surfaces form.

In summary, infants perceive the unity and boundaries of objects under a variety of conditions. They perceive an object as separate from any other object or surface that lies behind it, provided that the object is separated in depth from its background. Infants also perceive the visible ends of a partly

occluded object as connected behind the occluder, provided that the ends undergo a common translation. But infants do not perceive the unity and boundaries of objects under other conditions that are effective for adults. They do not seem to perceive two stationary adjacent objects as separate, even if their surfaces differ in color and texture and their edges are not aligned. Moreover, they do not perceive two stationary ends of a partly hidden object as connected, even if the ends are the same in color and texture and are placed in alignment. Finally, perception of suspended objects and of moving, partly occluded objects is not affected by the shapes of these objects or the colors and textures of their surfaces. All these findings can be described in a simple way. Infants appear to perceive objects in accordance with two principles.

PRINCIPLES OF OBJECT PERCEPTION

My account of object perception depends on certain assumptions about the infant's perception of surfaces. First, I assume that infants perceive surfaces at their proper distances and orientations in three-dimensional space. If two surfaces meet at a visible juncture, infants perceive that they are touching. If one surface partly occludes another, infants do not perceive the partly hidden surface to end where the occluding surface begins. If one surface is displaced, infants perceive the three-dimensional path of its movement. These assumptions are supported by a considerable body of research (for reviews, see Gibson & Spelke, 1982; von Hofsten, 1982b).

Second, I assume that infants distinguish between the relatively small surfaces of objects and the larger surfaces that form the background of most visual scenes. They distinguish the surfaces of manipulable objects from extended surfaces such as walls, floors, ceilings, and perhaps tabletops. This assumption is shared by others (Bower, 1979; Bresson & de Schonen, 1976–1977; Piaget, 1954), although the infant's differentiation of object and background surfaces has received little study. Object surfaces and background surfaces may be distinguished on the basis of the size of the region they occupy in the visual field: Infants may perceive an object surface if and only if they view a surface whose edges are contained entirely within the visual field (Bower, 1979; Bresson & de Schonen, 1976–1977). Alternatively, object surfaces and background surfaces might be distinguished on the basis of their real size, perhaps in relation to the size of the hand. These possibilities have not been investigated systematically.

Thus, an infant who faces a visual scene is assumed to perceive a three-dimensional layout of object surfaces and background surfaces, each of which is moving or still. The infant discovers which of the object surfaces lie on the same object by following two principles.

The first will be called the *connected surface principle*. It states that two surfaces pertain to the same object if they touch each other directly or through other object surfaces. Two surfaces otherwise pertain to distinct objects. More precisely, two points on any surfaces in a layout lie on the same object if, and only if, there exists a curve that lies only on object surfaces and that connects them. For example, this principle dictates that two adjacent objects are one unit, since all points on the objects lie on connected object surfaces. If two objects rest on the same background surface and are separated in depth, the principle dictates that they are separate. Any curve that connected points on these objects would necessarily lie partly in the air or on the background. Note that both pairs of objects would send adjacent projections to the eye. The connected surface principle refers to the spatial connectedness of surfaces in a three-dimensional layout, not to the contiguity of their two-dimensional projections.

The second principle will be called the *common movement principle* and is adapted from the Gestalt principle of common fate (Wertheimer, 1923). It states that two surfaces lie on the same object if they undergo a common translation through the layout: a movement that carries the surfaces from one place to another without destroying the connection between them. Two surfaces lie on different objects if one moves relative to the other in a manner that would disrupt any connection between them.

These principles are offered tentatively, for they rest on a narrow set of studies. For example, infants' perception of the boundaries of moving objects has just begun to be studied, and only a few rigid movements have been investigated. Certain non-rigid movements can also carry an object from place to place without destroying its connectivity: Walking movements are a prime example. Presented with lights undergoing the movements of a human walker, adults perceive a unitary, jointed object; a person (Johansson, 1978). We do not know whether infants would also perceive the unity of an object that moved non-rigidly. As this and other possibilities are tested, the common movement principle may need to be reformulated. It seems clear, however, that infants perceive obects by detecting some arrangements and movements of surfaces through a scene.

What is perceived when the connected surface and the common movement principles conflict? We do not know, but I think it likely that separate objects are always perceived in this case. Adults appear to perceive distinct objects whenever spatially separated surfaces move together. A flock of geese is never one object to us, nor is a stream of traffic. And Piaget's observations suggest that infants perceive two separate objects when adjacent surfaces move independently. This, too, is a question for further research.

The connected surface and the common movement principles are the only principles infants follow, I suggest, when they divide visual scenes into objects. In particular, infants do not follow any similarity principle, perceiving as a unit surfaces that are identical in color or texture or shape. Infants

also do not follow any form principles, grouping together surfaces so as to create objects with simple shapes and smooth edges. Although infants are sensitive to the colors, textures, and shapes of objects, they do not take account of these properties when they perceive an object's boundaries. In these respects, infants perceive objects differently from adults. When adults are presented with a scene consisting of unfamiliar objects, we tend to divide that scene into units so as to form the simplest, most regular objects that the scene allows. Infants of three and four months do not show this tendency.

DEVELOPING KNOWLEDGE OF OBJECTS

In closing, I consider how the infant's ability to perceive objects might develop. This ability may grow hand in hand with ur conceptions of objects and their properties.

Research on object perception in infancy provides some support for a hypothesis raised many years ago by Brunswik (Brunswik, 1956; Brunswik & Kamiya, 1953) and implicitly by others before him (Helmholtz, 1925; Mill, 1865). Brunswik suggested that all the Gestalt principles—all tendencies to perceive objects so as to form simple, regular configurations—are learned. These tendencies reflect acquired knowledge about the likely properties of objects. When he analyzed a variety of photographs of scenes, Brunswik found that nearby regions of a photograph were more likely to lie on the same object than distant regions, and that closed, symmetrical contours were more likely to enclose an object than open or asymmetrical ones. Thus, the properties of proximity, closure, and good form were predictors of object boundaries in these scenes. Brunswik hypothesized that children discover such predictive relationships through a kind of correlational learning, in which the Gestalt properties are assessed against other sources of information about objects. In this way, children learn to perceive in accordance with the Gestalt principles of organization.

One can imagine how learning could lead to the emergence of the principles of similarity, good continuation, and good form. If children initially perceive objects in accordance with the common movement and the connected surface principles, and if they are sensitive to the coloring and shapes of surfaces, then they could discover that the objects they see are likely to be uniformly colored and textured and that each object's color and texture are likely to differ from those of other objects. In addition, children could discover that objects often have smooth edges and simple shapes. Children might come to rely on the color and shape of an object to detect its boundaries as they discover that color and shape provide useful information about those boundaries.

Are the connected surface principle and the common movement principle also learned in a Brunswikian fashion, in the first three months of life? I think not. For if all principles of visual organization were learned, it is not obvious how the process of correlational learning could ever begin. One must have some ability to perceive objects, or one could never assess the validity of new sources of information about them. Moreover, it is likely that the initial ability to perceive objects is expressed through vision: young infants are clearly not adept at perceiving objects with their hands or ears. As the Gestalt psychologists maintained, our ability to learn about visual scenes seems to depend on an unlearned ability to perceive organization in these scenes (Koffka, 1935; Köhler, 1947).

Thus, some principles by which adults perceive objects may reflect our innate perceptual predispositions, whereas other principles may reflect the nature of the objects we have encountered. We might divide visible surfaces into objects by detecting their spatial continuity and their movements regardless of the nature of our visual world. But if we had grown up in a sufficiently different world, we might not carve arrays into units by analyzing their colors, textures, and forms.

These conclusions may pertain only to the development of perception, but I am intrigued by a different possibility. Our ability to perceive objects may be related to our ability to think about them. In particular, the initial principles of object perception may spring from a conception of what an object is.

What do we mean when we call something an object? I think we mean, roughly, that it is a physical entity that exists in some place, that all its parts are spatially interconnected, and that it will tend to maintain its connectedness as it moves. A handful of sand is not an object, for its individual grains are not interconnected. A body of water is not an object, for its unity is easily destroyed by displacing it in certain ways. When we call something an object, however, we do not mean that it is uniformly colored, smoothly contoured, or simply shaped. A twisted, multicolored piece of coral is just as much an object as a perfectly formed shell. The coral would not cease to be an object if its coloring and shape were made even more irregular, but only if it were broken into pieces. Uniformity of color and simplicity of shape are characteristic, but not essential, properties of objects. An object is in essence a coherent body that maintains its coherence as it moves.

These considerations suggest that the adult's perception of objects reflects knowledge of two kinds. The Gestalt form principles and the similarity principle appear to reflect knowledge about the characteristic attributes of common objects. The connected surface principle and the common movement principle appear to reflect knowledge about the essential nature of an object. Knowledge about the characteristic properties of objects may be acquired gradually over infancy and childhood, as children encounter objects and explore them. But knowledge of an object's essential nature may be shared, in part, by the youngest infant. It may first be ex-

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23 On Gaps Undetectable for Language Learners

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During the first years of their lives, children learning their mother tongue are exposed to a huge number of well-formed sentences, but they are provided with very little "negative" information, i.e., information about what sound sequences are not well-formed (cf. Braine 1971). This fact can help us to gain some insights into the workings of children's language acquisition capacity. In Dell (1981) I discussed some of its implications concerning the way optional phonological rules are acquired.[1] These had to do with the manner in which the language acquisition device (henceforth LAD) evaluates alternative hypotheses concerning the structural description of such rules, and their relative ordering in the grammar. In this article I extend my argument to the acquisition of exceptions and I furthermore suggest that under certain assumptions about the way the LAD stores primary linguistic data, some gaps in these data are undetectable for it.

French has a rule, call it LIQ, by which a word-final liquid optionally drops if preceded by an obstruent and followed by a pause or a consonant, e.g. *faut l'éteindre* "you've got to put it out" can be pronounced [foletɛ̃d], et *éteindre les feux* "to put out the fires" can be pronounced [etɛ̃dr lefö][2] or [etɛ̃dlefö]. The rule applies more frequently in fast and/or relaxed styles of diction, but its application is not compulsory even in the most informal styles.

[1]Its implications for general syntax are discussed in Baker (1978; 1979). For general assumptions about language acquisition, I follow Chomsky (1965, esp. 25–47; 1975).

[2]Shwa is inserted by rule EPEN, cf. below. Setting irrelevant details aside, the underlying representation of *éteindre* is /etɛ̃dr/, and more generally, all the words that show up phonetically as [XCC] before a pause have an underlying form /XCC/.