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Perception of objects and object boundaries by 3-month-old infants

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Perception of object boundaries was tested by habituating infants to an arrangement of two objects and then presenting test displays in which either one object appeared in a new position, changing the two-object configuration, or both objects appeared in new positions, preserving the two-object configuration. If infants perceived the objects as distinct units, they were expected to look equally at the two test displays, since both displays consisted of the same units in new positions. If infants perceived each two-object configuration as a single unit, in contrast, they were expected to look longer at the display that changed this configuration, since that display would present the infants with a unit that was new or altered. Two experiments provided evidence that objects were perceived as distinct units when they were spatially separated in depth, even if their images overlapped fully in the visual field. In contrast, objects were perceived as a single unit when they were adjacent in depth, even if the objects differed in colour, texture, and form and if both objects were stably and independently supported. Unlike adults, young infants do not appear to perceive object boundaries in accord with the Gestalt principles of similarity, good continuation, and good form, or in accord with implicit knowledge about gravity and relations of support. Infants do appear to perceive object boundaries by detecting information for the arrangement of surfaces in the three-dimensional layout.

The surface layout is specified by optical information such as textural, kinetic, and binocular invariants (see J. J. Gibson, 1979; Marr, 1982), and human infants, like adults, perceive surface positions, orientations, and movements by detecting some of this information (see Banks & Salapatek, 1983; E. Gibson & Spelke, 1983). For adults, this surface layout is organized into unitary, bounded, and persisting objects (see Koffka, 1935). The present experiments form part of an attempt to investigate the origins of this ability, by focusing on young infants' perception of object boundaries.

The ability to perceive object boundaries is of special interest, because the optical information for those boundaries appears to be highly inadequate. The surfaces in any visual scene contact, support, and partly conceal each other in complex patterns; no optical invariant appears to specify which of these surfaces lie on a single object and which lie on distinct objects that touch or ovelap. Adults, nevertheless, can perceive object boudaries in multiple ways. For example, we may group surfaces into maximally simple and regular units in accord with Gestalt principles of organization, we may analyse the support relationships among surfaces in accord with tacit knowledge of gravity and its constraints on surface arrangements, and we may recognize certain collections of surfaces as objects of known kinds. But where do these tendencies originate? Does object perception depend on the acquisition of knowledge about surfaces and their probable arrangements, or does it develop from initial, intrinsic capacities to organize visual experience?

According to Piaget (1954) and many empiricists (e.g. Berkeley, 1709/1910; Titchener, 1909), object perception depends on knowledge acquired through the child's activity. Infants do not experience a world of objects but a patchwork of colours reflected from the visible surfaces in a scene. As infants begin to reach for visible surfaces, they gradually construct a set of notions about objects, and these notions serve as a basis for perceiving object boundaries. For example, infants may learn that surfaces that have colinear edges tend to move together when they are grasped and displaced, and this notion may lead them to perceive object boundaries in accord with a principle of good continuation (see Brunswik, 1956; Hochberg, 1968). The Gestalt psychologists provide a contrasting view. Infants begin with a propensity to confer the simplest organization on visual arrays, grouping regions of the layout into the most regular units (Koffka, 1935). Even before the onset of visually guided reaching, infants perceive object boundaries by analysing the smoothness of surface edges, the homogeneity of surface colouring, and the simplicity of surface shapes. Learning about objects develops on the basis of this perceptual capacity, supplementing but never overturning the initial organizing tendency.

Although this controversy has a long history, only a few experiments have focused on infants' perception of object boundaries. Piaget (1954) investigated one infant's perception of objects by observing the infant's patterns of object-directed reaching. He found that the infant, aged 6–10 months, would reach for a small object when it was dangled in the air or perched on someone's fingertips but not when it was placed firmly upon a second, larger object of a different colour and texture. In the latter case, the infant either reached for the supporting object or ceased reaching altogether. Piaget suggested that infants fail to perceive the boundary between two objects in a support relationship. Piaget's observation has been replicated with younger infants (Wishart & Bower, 1984), but further experiments call his conclusion into question. When presented with two objects within reaching distance, infants have been found to reach primarily for the nearer object (Yonas & Granrud, 1984), and this activity tends to interfere with activities directed at the other object (Schonen & Bresson, 1985; Willats, 1985). Since Piaget's supporting object was always closer than the object it supported, this reaching preference may account for his infant's failure to reach for the supported object (Bresson *et al.*, 1977).

A more recent experiment eliminated this source of difficulty by comparing infants' reaching for configurations of two objects that were arranged in depth (Hofsten & Spelke, 1985). Five-month-old infants were allowed to reach for two objects that were either adjacent or separated in depth. In both displays, a smaller object was centred in front of a larger object such that the latter provided all the external borders of the display. The adjacency or separation of the objects was produced by varying the thickness of the closer object. Infants reached primarily for the smaller, closer object when the objects were separated in depth and for the larger, more distant object when the objects were adjacent. Given that infants tend to reach for the nearer of two perceptually distinct objects (Yonas & Granrud, 1984), and given that infants tend to reach for objects by grasping at their external borders (Spelke & Hofsten, 1986), these reaching patterns suggested that the two objects were perceived as distinct units when they were separated and as one unit when they were adjacent.

Hofsten & Spelke's (1985) findings would seem to provide evidence against both developmental accounts presented above. If young infants perceive visual arrays as a coloured mosaic, then their organization of a two-object display should not be influenced by the depth relation between the objects. If young infants organize visual arrays in accord with Gestalt principles, then they should perceive two objects as distinct units even when they are adjacent. Nevertheless, three aspects of this study limit the conclusions that can be drawn from it. First, the study focused on only one index of object perception: object-directed reaching. Findings concerning infants' perception of objects would be more convincing if studies using different methods converged on the same conclusions (see Spelke, 1985*a*; Spelke & Hofsten, 1986; Stiles-Davis, 1986). Second, since visually guided reaching provided the dependent measure, the infants in this research were necessarily past the age of its onset (about 4½ months). It is possible, as empiricist and Piagetian accounts suggest, that an initial tendency to perceive the visual world as a mosaic was superseded by developments brought on by the coordination of vision and prehension. Third, the studies of object-directed reaching presented adjacent objects in rather special support relationships: in Piaget's studies, one object was supported by the other; in Hofsten & Spelke's studies, one object was suspended in front of the other with no visible means of support. It is possible that infants (and even adults) will expect two objects to move together as a single unit when one supports the other or when both are suspended in mid-air, but not under conditions in which each object is supported independently of the other.

The present experiments address these limitations. Object perception was investigated by means of a method that required no manual activity and no coordination of vision and prehension. The subjects in these experiments were 3 months old—well below the age of onset of visually guided reaching and manipulation. Finally, the experiments varied systematically the conditions under which objects were supported. In Expt 1, two objects were invisibly suspended, as in Hofsten & Spelke's (1985) studies. In Expt 2, two objects were placed directly on a horizontal surface such that each was stably and independently supported. In both studies, infants were presented with objects of different colours, textures, sizes, and shapes that were adjacent or separated in depth. The experiments investigated whether infants would perceive the objects' boundaries by analysing the spatial arrangements, the Gestalt properties, and/or the support relationships among their visible surfaces. A subsidiary experiment investigated whether adults perceived object boundaries in these displays by analysing these three sources of information.

In these experiments, object perception was investigated by means of a habituation of looking time method. The method rests on findings that infants who are habituated to a display containing one object will generalize habituation to displays in which the same object appears in a new position (e.g. Pêcheux & Vurpillot, in Pêcheux, 1981; Bullinger, 1985) and/or a new relation to other objects (e.g. Kellman & Spelke, 1983) and will dishabituate to displays in which that object is replaced by a new object of a different shape (e.g. Day & McKenzie, 1973; Caron *et al.*, 1979) or size (e.g. Day & McKenzie, 1981). Each infant was habituated to one display of two objects, and then he or she was tested with two new displays of those objects. In one display, both objects appeared in new positions, preserving the spatial relationship between them. In the other display, one object appeared in a new position such that the spatial relationship between the objects was changed. If infants perceived the two objects in the original display as distinct units, they were expected to show low looking to both test displays, each of which presented the same two objects in new positions and/or arrangements. If infants perceived the two objects in the original display as a single unit, they were expected to look longer at the display in which one object was displaced. Such infants should generalize habituation to the display in which both objects were displaced together, because that display presented the same two-object unit in a new position. They should dishabituate to the display in which one object was displaced, because they should perceive that display as presenting either a new object with a different shape or a broken version of the original object.

Experiment 1

Each infant was presented with two objects arranged in depth, one object suspended in front of the other such that the image of the more distant object completely encircled that of the closer object in the infant's visual field. For half the infants, the objects were adjacent in depth; for the other infants, they were separated in depth. After habituation to this display, the infants in both conditions were tested with new displays in which one or both objects appeared in closer positions. Perception of the unity or the distinctness of the two objects was inferred from infants' patterns of dishabituation.

Method

Subjects. Participants were 16 male and 16 female infants, born of full-term pregnancies and residing in the Philadelphia area. At the time of testing, the infants ranged in age from 2 months 22 days to 3 months 22 days (mean age 3 months 6 days). Four additional babies failed to complete the study due to fussiness.

Display and apparatus. Each infant sat in an infant seat facing a 60 × 60 × 60 cm display box, painted white and lit from above by fluorescent lights. The visual displays appeared at the infant's eye level within this box. Each display consisted of two wooden blocks arranged in depth: a larger and more distant block that was 15cm tall and 31 cm wide, and a smaller, closer block that was 10 cm tall and 15 cm wide. The larger block was covered with brown, rust and yellow plaid wool fabric; the smaller block was painted shiny green and covered with silver stars. These blocks were supported from the back of the display box by rods, so that each object was centred in the display. The larger object was positioned 21 cm above the stage floor, and the smaller object was positioned 23cm above the floor.

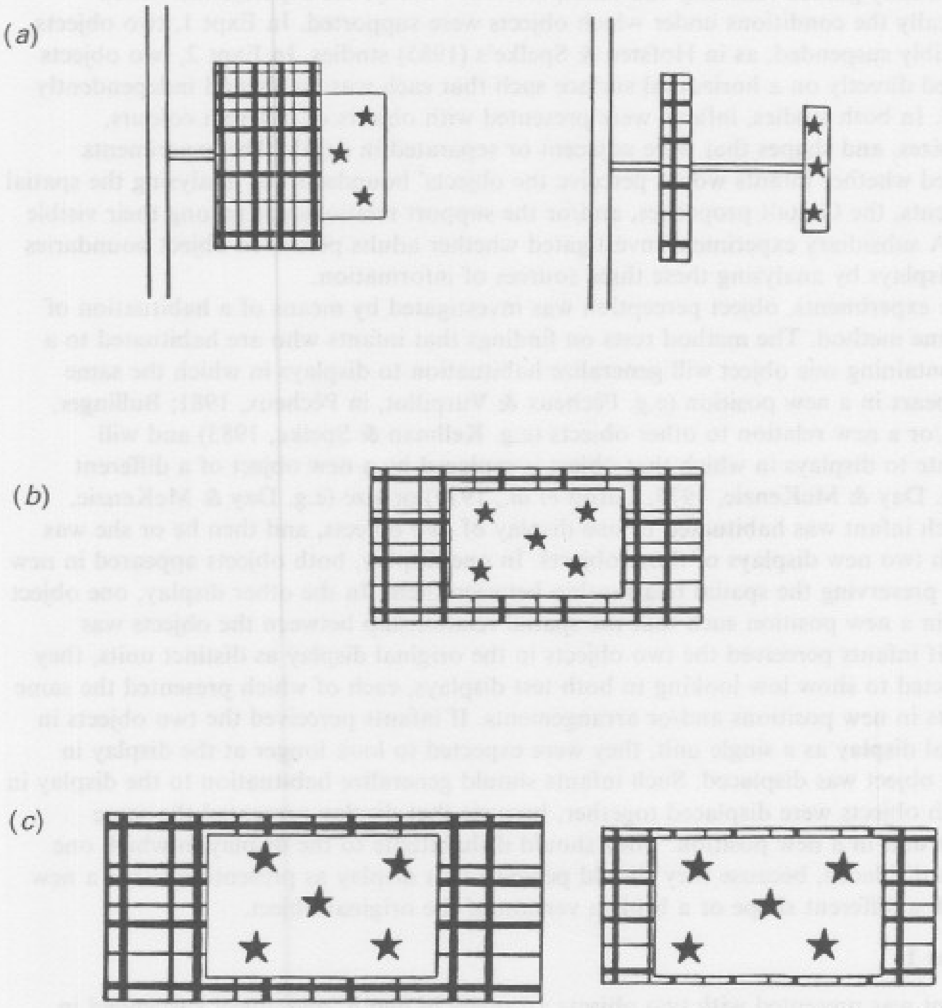

Figure 1. (*a*) Side views of the adjacent objects display (left) and the separated objects display (right); (*b*) front view of the habituation display; (*c*) front views of the test displays with both objects displaced forward (left) and with one object displaced forward (right).

In one display, the two blocks were rather thick and were adjacent in depth: the larger, 8 cm thick block was placed directly behind the smaller, 5 cm thick block (Fig. 1*a*). In the other display, the blocks were thinner—each was 2 cm thick—and were separated in depth by a gap of 9 cm (Fig. 1*a*). Only the thickness of the blocks, their adjacency or separation in depth, and the distance of the front surface of the more distant block distinguished these displays.

During the habituation period, each two-object display was presented so that the large block was 5 cm from the back of the stage. The front surface of the small block was initially 67 cm away from the infant in both the adjacent and the separated objects displays, and the front surface of the large block was initially 72 cm (adjacent objects display) or 78 cm (separated objects display) from the infant (Fig. 1*b*). During the test period, the distance of one or both objects was changed by pushing on the rods by which the objects were supported. Either both the objects, or just the smaller object, appeared in a position 23 cm further from the back wall and closer to the infant (Fig. 1*c*).

The display box was surrounded by curtains. An additional curtain, suspended in front of the box, could be raised or lowered to reveal or conceal a display. Small openings in the side curtains allowed two observers to monitor an infant's looking at the objects from positions to the left and the right of the display box. The observers scored the infant's looking time by depressing buttons that were connected to a concealed microcomputer. The curtain was raised and lowered by hand on cue from the microcomputer.

Design. The experiment consisted of two conditions: the 16 infants in one condition were habituated to the adjacent objects, and the 16 infants in the other condition were habituated to the separated objects. After habituation, infants in both conditions were presented with six alternating test trials in which both objects, or only the smaller object, appeared in the forward position. Within each experimental condition, sex of infant and order of test trials were counterbalanced.

Procedure. An infant-control habituation procedure was used. After the infant was seated in front of the display box and the room lights were dimmed, the curtain was raised to reveal the objects in their original positions, initiating the first habituation trial. Presentation of the habituation display continued until the baby had looked at the display for at least 1 s and then had looked away continuously for 2 s. The presentation ended with the lowering of the curtain. The curtain was raised again 3 s later, revealing the same display and initiating the next trial. Trials continued until a criterion of habituation was met or until 14 trials had been presented, whichever came first. The criterion was a 50 per cent decline in total looking time on three consecutive trials, relative to the infant's looking time on the first three trials on which he or she had looked for a total of at least 12 s. Thus each infant received a minimum of 6 and a maximum of 14 habituation trials.

At the end of the habituation sequence, the curtain was lowered, the blocks were placed in the positions they would assume for the first test trial, and the curtain was raised to begin that trial. During the test sequence, the test displays were presented in alternation for three trials each. The position of the more distant object was changed between trials while the curtain was lowered. The test trials followed the same procedure as the habituation trials.

Looking time was monitored independently by two observers who could not see the displays and who were ignorant of the experimental condition and test trial order of each baby. The more experienced of these observers was designated the primary observer; his or her recording served as the data for the experiment and as the basis for ending each trial and calculating the habituation criteria. Inter-observer agreement—the proportion of time on which both observers recorded that the baby was either looking or not looking at a display—averaged 0·85.

Results

Figure 2 presents the duration of looking time during the habituation and the test trials for the infants in each experimental condition. During the habituation sequence, the infants received an average of nine trials (adjacent condition) and eight trials (separated condition). Five infants, three in the adjacent condition, failed to reach the criterion of habituation within the 14 trials that were given. After habituation, the infants who had been presented with the objects that were adjacent in depth looked longer at the display in which one object was moved forward. This tendency was not shown by the infants who had been presented with the objects that were separated in depth.

A 2 (condition) × 2 (test order) × 3 (trial block) × 2 (test display) analysis of variance on test-trial looking times confirmed these findings. The looking time data were log transformed for this analysis, since looking times during the test trials were positively skewed. This analysis revealed a significant interaction of condition with test display ($F = 6{\cdot}08$, d.f. $= 1,28$, $P < 0{\cdot}025$). The only other significant effect in the analysis was a main effect of trial block ($F = 7{\cdot}56$, d.f. $= 2, 56$, $P < 0{\cdot}01$) indicating that looking times declined over the three pairs of test trials.

To investigate the critical interaction in more detail, separate t tests for each of the experimental conditions compared looking time to the display in which only one object was moved to looking time to the display in which both objects were moved. The infants who had been habituated to the adjacent objects looked significantly longer, over the six test trials, at the test display in which the arrangement of the objects was changed ($t = 1{\cdot}79$, d.f. $= 15$, $P < 0{\cdot}05$, one-tailed). Although the infants who had been habituated to the separated objects appeared to look longer at the test display in which the arrangement of

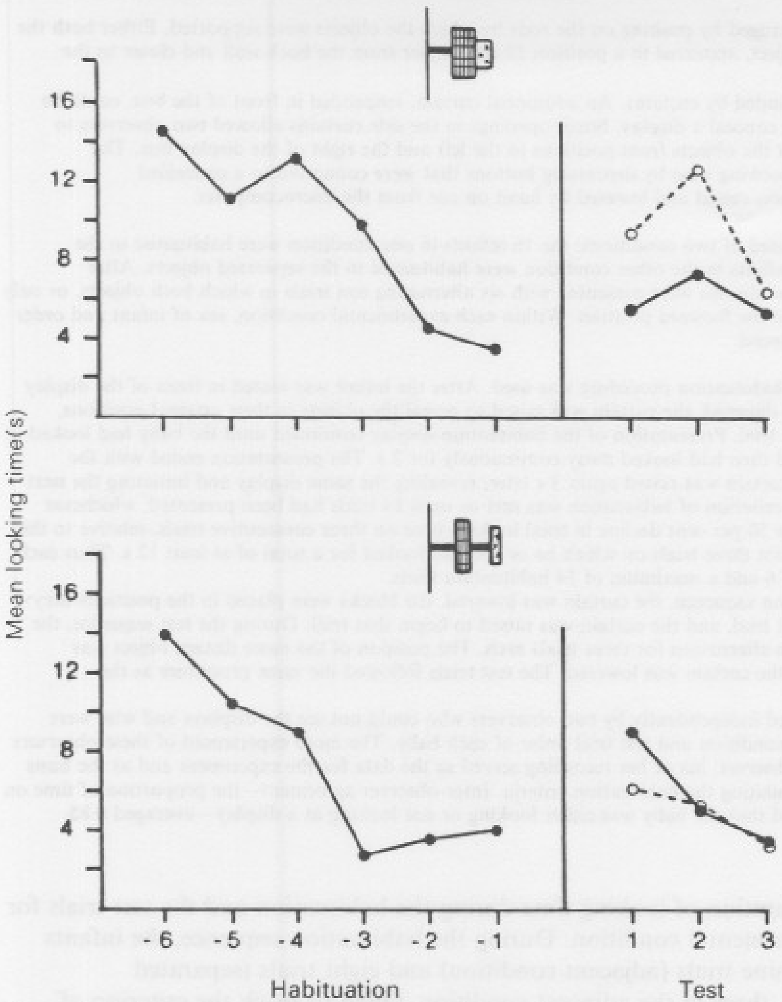

Figure 2. Looking times during the habituation and test trials of Expt 1. ●——●, two forward; ○----○, one forward.

the objects was preserved, this tendency was not significant ($t = 1{\cdot}16$, d.f. $= 15$, $P > 0{\cdot}20$, two-tailed).

The infants in the adjacent condition consistently preferred the test display with one object in a forward position: 13 of the 16 infants in that adjacent condition looked longer at this rearranged test display ($P < 0{\cdot}025$, sign test). In contrast, only six of 16 infants in the separated condition looked longer at the test display with one object moved forward ($P > 0{\cdot}10$). This interaction is significant ($\chi^2 = 6{\cdot}35$, $P < 0{\cdot}025$).*

*The analysis described in the text is one of four that were conducted. Following the procedure of our previous experiments (e.g. Kellman & Spelke, 1983), three additional measures of test trial looking patterns were analysed: the duration of looking during the six test trials, the proportion of looking time devoted to a given test display on each of the three pairs of test trials, and the recovery from habituation on the first pair of test trials. The analyses of log transformed looking scores, proportion scores, and recovery scores yielded the same finding: a significantly greater preference for the rearranged display in the adjacent objects condition than in the separated objects condition. The same effect was obtained in the analysis of raw looking times, but it was only marginally significant.

Discussion

After habituation to the separated objects, infants showed no differential dishabituation to a display in which the objects appeared in a new arrangement and to a display in which the objects were displaced but appeared in their original arrangement. After habituation to the adjacent objects, infants showed greater dishabituation to a display in which the objects appeared in a new arrangement. This pattern suggests that the infants perceived the separated objects as distinct units and the adjacent objects as a single unit.

The findings of this experiment are not conclusive, however, for two reasons. First, it is possible that the infants in the adjacent condition dishabituated to a change in the spatial relationship between the objects, from adjacent to separated, and not to a change in the perceived boundaries of the objects. Although the spatial relationship changed in the separated condition as well—from a small separation in depth to a larger one—that change might have been perceptually less prominent.

Second, it is possible that differential reactions to the adjacent and separated objects derived from the fact that the objects lacked visible support. In most scenes, separate stationary objects touch each other only if one supports the other or if both are supported by a third object or surface. When an object without apparent support touches a second object in mid-air, it is usually attached to that object. The infants in Expt 1, therefore, might have perceived the adjacent objects as a single unit by virtue of their tacit knowledge about gravity and the conditions for object support. Suggestive evidence against this possibility comes from an experiment by Keil (1979). Using a surprise method, Keil found that 18-month-old infants correctly anticipated that an object would fall when the objects that supported it were removed, but that 12-month-old infants did not. The younger infants did not appear to take account of an object's source of support in determining how the object would move. It is possible, nevertheless, that knowledge about support relationships begins to guide perception of object boundaries before it guides predictions about object movement.

Experiment 2 investigated these possibilities. Like Expt 1, it focused on infants' perception of the boundaries of two objects that were adjacent or separated in depth. In this experiment, however, the objects were presented on a flat, horizontal surface such that each was stably and independently supported by that surface. Infants' perception of the unity vs. distinctness of the objects was tested by habituating each infant to the adjacent objects or the separated objects and then presenting the infant with displays in which one or both objects were moved laterally rather than in depth. The sideways displacement preserved the spatial relationship of the objects: the adjacent objects remained adjacent and the separated objects remained separated. If infants perceived the adjacent objects as one unit, they were expected to look longer at the display in which one object was displaced; if they perceived the adjacent objects as distinct units that were touching, they were expected to look equally at the two test displays.

Experiment 2

Method

The method was identical to that of Expt 1, except as follows:

Subjects. Thirty-two infants aged 2 months 14 days to 4 months 2 days (mean age 3 months 6 days) participated in the study. Seven additional infants failed to complete the study because of fussiness.

Displays and apparatus. Each display consisted of a larger, more distant block (15 cm tall × 31 cm wide) and a smaller, closer block (10 cm tall × 10 cm wide). Half of the larger block was covered with blue corduroy material, and the other half was covered with an orange and yellow lined material.*The smaller block was painted

*The more distant object was covered with two fabrics so as to enhance the distinctiveness of the two test displays. If a uniform covering were used, the test displays would have been nearly identical except for a mirror image reflection—a difficult discrimination for young children.

green with gold stars arranged haphazardly upon it. In both displays, the large block was 8 cm thick. The small block was 9 cm thick in the adjacent objects display and 3 cm thick in the separated objects display (Fig. 3*a*). Only the thickness of the small block and its adjacency or separation in depth from the large block differentiated these displays.

Throughout the study, these blocks stood on the white floor of the display. The front surface of the small block was 48 cm from the infant, and the front surface of the large block was 57 cm from the infant. During the habituation period, half the infants saw the blocks on the right side of the display: the centre of the small block was 11 cm to the right of centre and the centre of the large block was 9 cm to the right of centre (Fig. 3*b*). The other infants were habituated to the objects on the left side of the display. During the test, either the little object or both objects were displaced 11 cm toward the centre of the display, while keeping constant the distances of each object from the other (Fig. 3*c*). The image of the larger object continued to surround that of the smaller object in both test displays. Objects were positioned in the display by hand between the test trials, while the curtain was closed.

Design and procedure. These were the same as Expt 1. Inter-observer agreement averaged 0·87.

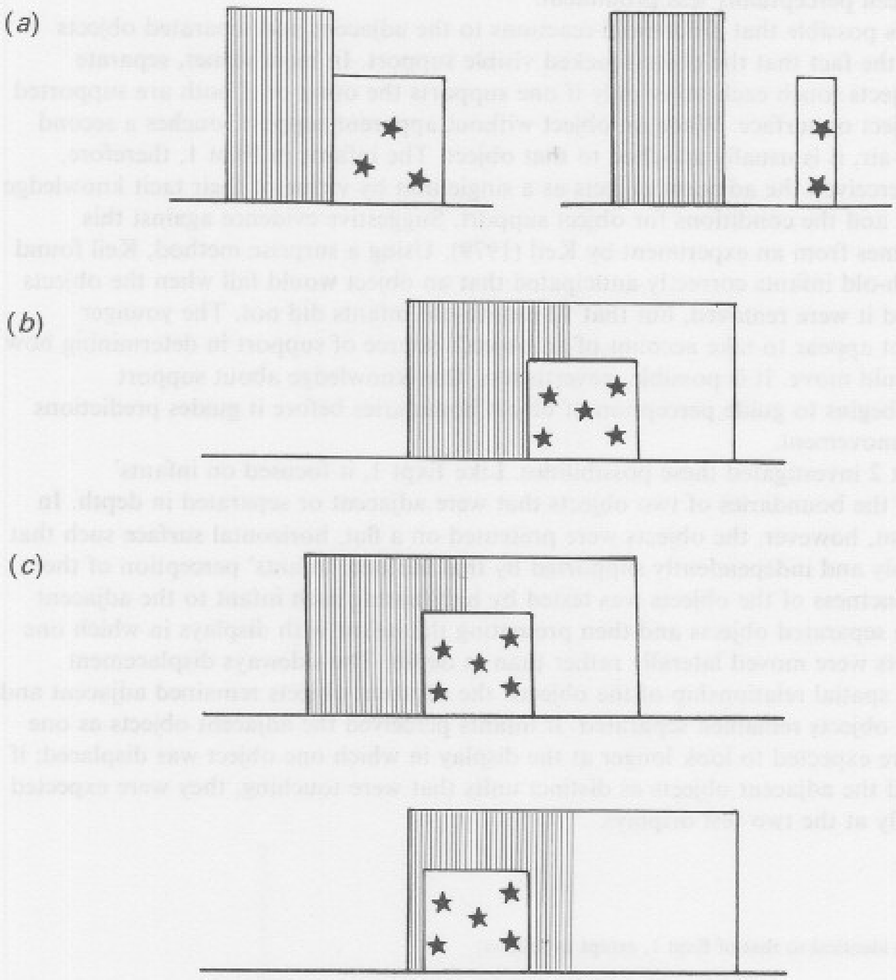

Figure 3. (*a*) Side views of the adjacent objects display (left) and the separated objects display (right); (*b*) front view of the habituation display; (*c*) front view of the test displays with both objects displaced sideways (top) and with one object displaced sideways (bottom).

Results

Infants received an average of nine and eight habituation trials in the adjacent and separated conditions, respectively. Three infants, two in the adjacent condition, failed to reach the criterion of habituation. Figure 4 presents the duration of looking times for the infants in the adjacent and the separated conditions. After habituation, the infants in the adjacent condition looked longer at the display in which one object was moved to the side. Infants in the separated condition did not show this preference. The analysis of log transformed looking times revealed that this interaction of habituation condition with test display preference was significant ($F = 4{\cdot}99$, d.f. = 1,28, $P < 0{\cdot}05$). The only other significant factor in the analysis was trial block ($F = 6{\cdot}64$, d.f. = 1,56, $P < 0{\cdot}01$): looking times declined over the three pairs of trials.

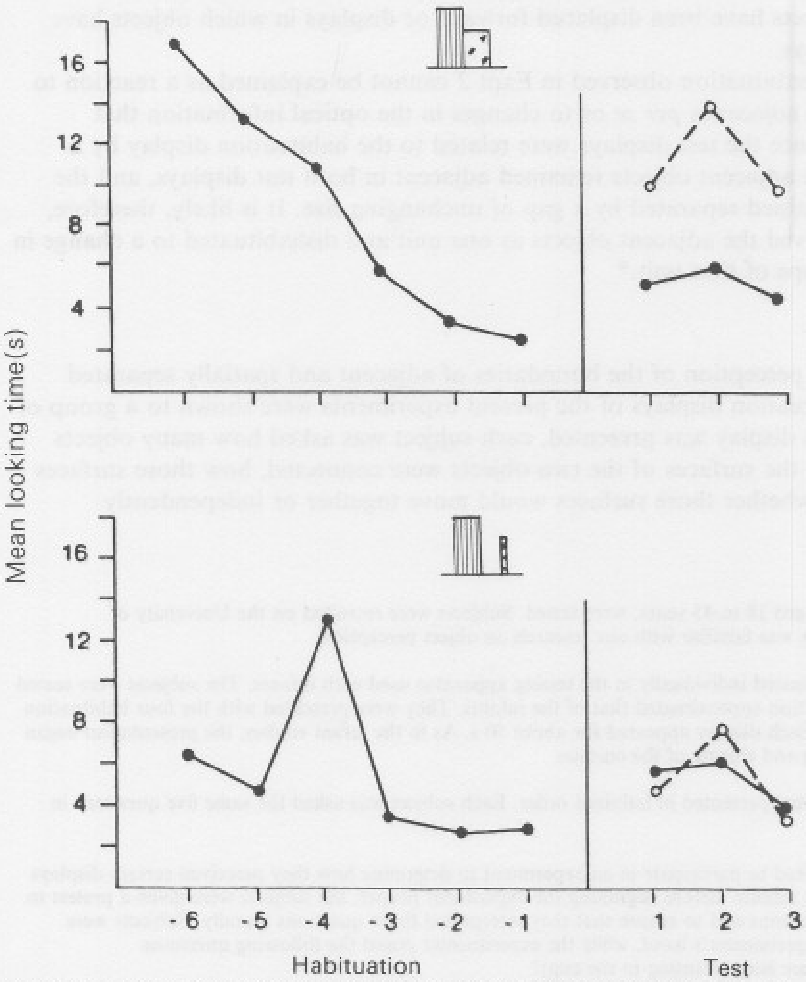

Figure 4. Looking times during the habituation and test trials of Expt 2. ●——●, two sideways; ○----○, one sideways.

The infants who were habituated to the adjacent objects looked reliably longer at the display in which the arrangement of objects was changed ($t = 1{\cdot}89$, d.f. = 15, $P < 0{\cdot}05$, one-tailed); 13 of 16 infants showed this preference ($P < 0{\cdot}025$, sign test). In contrast, the infants who were habituated to the separated objects showed no such preference ($t = 0{\cdot}02$, d.f. = 15, $P > 0{\cdot}20$); five of 16 infants in the separated condition looked longer at the display with the altered arrangment ($P > 0{\cdot}10$). The effect of experimental condition on the number of subjects preffering the rearranged display is significant ($\chi^2 = 8{\cdot}13$, $P < 0.01$).*

*Analyses of raw looking times, of proportion scores, and of recovery scores yielded the same results: there was a significantly greater preference for the rearranged display in the adjacent objects condition than in the separated objects condition.

Discussion

The findings of Expt 2 agree closely with those of Expt 1. Infants who were habituated to the objects that were adjacent in depth subsequently looked longer at a display in which one object was displaced, changing the objects' arrangement, than at a display in which both objects were displaced, preserving their arrangement. Infants who were habituated to objects that were separated in depth subsequently looked equally at the two test displays. The same patterns of dishabituation are observed, therefore, whether infants view objects that are suspended or objects that stand on the ground, and whether infants are tested with displays in which objects have been displaced forward or displays in which objects have been displaced sideways.

The patterns of dishabituation observed in Expt 2 cannot be explained as a reaction to change of the objects' adjacency *per se* or to changes in the optical information that specifies adjacency. Since the test displays were related to the habituation display by a lateral translation, the adjacent objects remained adjacent in both test displays, and the separated objects remained separated by a gap of unchanging size. It is likely, therefore, that the infants perceived the adjacent objects as one unit and dishabituated to a change in the identity or the shape of that unit.*

Experiment 3

To investigate adults' perception of the boundaries of adjacent and spatially separated objects, the four habituation displays of the present experiments were shown to a group of adult subjects. After a display was presented, each subject was asked how many objects were present, whether the surfaces of the two objects were connected, how those surfaces were supported, and whether those surfaces would move together or independently.

Method

Subjects. Twelve subjects, aged 18 to 45 years, were tested. Subjects were recruited on the University of Pennsylvania campus. None was familiar with our research on object perception.

Displays. Each subject was tested individually in the testing apparatus used with infants. The subjects were seated such that their viewing position approximated that of the infants. They were presented with the four habituation displays shown to infants. Each display appeared for about 50 s. As in the infant studies, the presentation began and ended with the opening and closing of the curtain.

Design. The four displays were presented in latinized order. Each subject was asked the same five questions in constant order (see below).

Procedure. Subjects were asked to participate in an experiment to determine how they perceived certain displays that have been studied with infants. Before beginning the experiment proper, the subjects were given a pretest to acquaint them with our questions and to ensure that they interpreted those questions literally. Subjects were shown a cup, held in the experimenter's hand, while the experimenter posed the following questions:

1. How many objects are here (pointing to the cup)?
2. Is this (pointing to the handle) connected to this (pointing to the bowl)?
3. How is this (pointing to the handle) supported?
4. How is this (pointing to the bowl) supported?
5. If I were to move this (pointing to the handle) from here (original position) to here (pointing to a position 10 cm above the handle, without moving the handle), what would happen to this (pointing to the bowl)?

After the subject had answered the questions, the experimenter presented a cup sitting on a saucer. The same

*There is a subtle alternative to this conclusion: Infants might perceive two adjacent objects as separate units, but the regions of contact between such objects might have special status. Thus, infants might dishabituate to any displacements of an array which changed this special region of contact but not to displacements which changed to an equal extent the spatial relation of objects that were not in contact. It would not be easy to distinguish these possibilities in the present experimental context. To our knowledge, however, the claim that infants attend to regions of object contact has no independent experimental support, whereas the claim that infants perceive adjacent objects as a single unit is supported by three bodies of independent research (see General discussion).

questions were posed, with the experimenter pointing alternately to the bowl of the cup and to the saucer. These questions were always asked in the above order. Note that the saucer, the cup, and its parts were never named by the experimenter, and that no determiners or quantifiers appeared in the questions. Names, determiners, and quantifiers were avoided so as not to bias, through language, the subject's organization of the display.

Following this pretest, the experiment began. The subject was positioned in front of the display box, and the curtain was opened to reveal the first display. After viewing the display for 10 s, the experimenter posed the same five questions. For question 2, she pointed in sequence to the front surface of the smaller object and the front surface of the larger object. For questions 3 and 4, she pointed to the front surface of the smaller and larger objects, respectively. For question 5, she pointed first to the front surface of the smaller object, then to a position that was either 23 cm closer to the subject or 11 cm to the side, and finally to the front surface of the larger object. Thus, she asked about the effect of moving the smaller object on the position of the larger object, using movements that paralleled the displacements in the infant experiments: a forward movement for the displays with suspended objects and a lateral movement for the displays with objects on the ground. After the subject answered the last question, the curtain was closed and the display was changed for the next trial.

Results

For the pretest questions, all the subjects reported that the cup was one connected object whose parts would move together and whose handle was supported by virtue of its connection to the bowl, which was supported by the experimenter's hand. All the subjects reported that the cup and the saucer were two distinct objects that would move independently and that were supported by the surfaces beneath them.

Table 1 presents the findings of the experiment. With near unanimity, the subjects judged that all the displays consisted of two objects. In some displays, these objects were judged to be connected and movable as a whole; in other displays, the objects were judged to be separate and independently movable.

Table 1. Judgements by adults of the connectedness, mobility, and support relationships among objects

	Objects suspended		Objects on ground	
	Adjacent	Separated	Adjacent	Separated
1. How many objects?				
One	1	1	0	0
Two	11	11	12	12
2. Connected?				
Yes	9	4	1	1
No	3	8	11	11
3. Small object supported				
By large	8	5	0	1
Independently	4	7	12	11
4. Large object supported				
By small	0	0	0	1
Independently	12	12	12	11
5. Objects will move				
Together	8	5	1	1
Separately	4	7	11	11

Judgements about the connectedness or separateness of the objects appeared to be influenced by the objects' source of support. To analyse this effect, the connectedness judgements for the supported vs. the suspended objects were converted to difference scores (from $+2$ to -2) and were analysed by a Wilcoxon test. Subjects judged more often that the supported objects were separate than that the suspended objects were separate ($P<0{\cdot}02$). Connectedness judgements were only marginally affected by the objects' adjacency or spatial separation ($P<0{\cdot}10$, Wilcoxon test).

Similarly, the subjects' predictions about the ways the objects would move were affected by the objects' support relationships. Wilcoxon tests revealed that subjects judged more often that the objects on the ground were independently movable than that the suspended objects were independently movable ($P<0{\cdot}005$). These judgements were not affected by the objects' adjacency or separation ($P<0{\cdot}2$).

Although the spatial relationship between the objects did not have a large effect on the subjects' judgements, it appeared to influence the judgements of connectedness and movability for the suspended objects. The subjects were more apt to judge that the suspended objects were connected and would move together when the objects were adjacent than when they were separated. When the judgements for the suspended objects were converted to difference scores (from $+1$ to -1) and were analysed separately by Wilcoxon tests, this effect was significant for the connectedness judgements ($P<0{\cdot}05$) although not for the movability judgements ($P>0{\cdot}20$).

Finally, the subjects judged nearly unanimously that the two objects in the on-the-ground displays were supported by the table, and that the larger object in the suspended displays was supported externally, by suspension wires or by rods attached to the background. Subjects were divided in their judgements about the source of support of the small object in the suspended displays. Wilcoxon tests revealed that support judgements for the small object were influenced by the support condition ($P<0{\cdot}005$), but not by the objects' adjacency or separation in depth ($P<0{\cdot}20$). The spatial relationship between the objects appeared to influence judgements of the objects' support when the suspended objects were considered separately: adults judged more often that the small object was supported by the larger object when the objects touched than when they did not ($P<0{\cdot}02$).

Discussion

The findings of this experiment contrast in three respects with those of the experiments with infants. First, adults judged that all the displays consisted of two objects, even when the objects were adjacent. The distinctness of the adjacent objects was given by configurational properties of the array, since the surfaces of the two objects differed in colour and texture, they were not aligned, and each object formed a regularly shaped rectangular unit. Unlike infants, adults evidently perceived the objects' boundaries in accord with some or all the Gestalt principles of similarity, good continuation, and good form.

Second, adults' judgements of the objects' connectedness or separation and of their common or independent movability were affected by the conditions of object support. Adults were more apt to judge that the two objects were not connected and were separately movable when the objects stood stably on a supporting surface than when they were suspended in the air. Adults evidently took account of the support relations among surfaces in judging whether surfaces were connected and how surfaces would move. This performance contrasts with that of the infants, whose reactions to the common or independent displacements of the two objects were unaffected by the objects' apparent source of support.

Finally, the adults' judgements were not in general affected by the adjacency or separateness of the objects. Adults do not appear to perceive object boundaries solely, or even primarily, by analysing the connectedness or separation of surfaces in depth. Here, the contrast with infants is greatest, since the adjacency or separateness of objects was the only factor that appeared to influence infants' perception of object boundaries.

Although the factor of adjacency or separation did not in general affect adults' judgements, it did appear to exert an effect on judgements of the connectedness of the suspended objects: adults were more apt to judge that two suspended objects were connected if the objects were adjacent. For adults, it appears that the adjacency or separateness of objects can provide information about object boundaries, but this information is subsidiary to information about the objects' shapes and support relationships. When objects of different colours, textures, and forms can be seen to be stably and independently supported, adults perceive the objects as distinct units whether they are separated or touching.

General discussion

The present experiments provide evidence that 3-month-old infants are sensitive to rather subtle distinctions between the arrangements of surfaces in depth, and that infants use perceived depth relations among surfaces as information for the boundaries of objects. The findings suggest that infants, unlike adults, do not perceive object boundaries in accord with Gestalt principles of organization or in accord with an analysis of the source of an object's support. We consider each conclusion in turn.

Perception of surfaces arranged in depth

In two experiments, infants who were habituated to objects that were adjacent in depth showed different patterns of dishabituation from infants who were habituated to objects that were separated in depth. We may conclude, therefore, that infants discriminated the original adjacent and separated objects displays. The ability to discriminate these displays is of interest in itself, because the displays were quite similar. The objects in both displays had front surfaces of the same sizes, textures, and colours; in Expt 2, these front surfaces appeared at the same distances from the baby and from each other. Only the thickness of the closer object and the depth relation between the objects distinguished the displays. Since these differences could not be seen from a central, stationary viewing position,* the spatial relationship between the objects was probably detected as the infants moved their heads and observed the optical changes consequent on head movements.

In particular, head movements produced different patterns of texture displacement and accretion/deletion in the two displays (Gibson *et al.*, 1969; Kaplan, 1969). In both the adjacent and the separated objects displays, head movements caused texture on the more distant object and on the sides of the nearer object to move relative to the edges of the front surfaces of the nearer object, and to appear and disappear at those edges. In the separated display, however, head movements produced texture displacement and accretion/deletion at the edges of the side surfaces of the nearer object as well. Thus the accretion/deletion patterns produced by the two displays were somewhat different. Young infants have been found to be sensitive to the patterns of texture displacement and accretion/deletion that are produced when two flat surfaces are arranged in depth, and detection of these patterns leads infants to perceive both the relative distance (Carroll & Gibson, 1981; Granrud & Hofsten, 1984) and the unity and form (Kaufmann-Hayoz & Kaufmann, 1984) of a surface. The present studies suggest that infants are also sensitive to the more complex patterns of texture displacement and accretion/deletion produced by three-dimensional objects, and that they perceive arrangements of objects in depth by detecting this information.

Perception of object boundaries

Although sensitivity to patterns of texture displacement and accretion/deletion can account for the discriminability of the adjacent and the separated object displays, it cannot account

*Indeed, adults who were shown photographs of each pair of displays, taken with the camera at the infants' station point, were unable to report whether the two objects in each display were adjacent or separated.

for the pattern of dishabituation shown by the infants in Expt 2. Infants who were habituated to the adjacent objects subsequently looked longer at the display in which one object was displaced than at a display in which both objects were displaced together, even though the two test displays presented adjacent objects with the same patterns of texture displacement and accretion/deletion as the habituation display. This pattern of dishabituation could not have stemmed from a general tendency to look longer at displays that change the arrangement of two objects, since such a tendency was not shown by infants who were habituated to the separated objects: infants responded to the two objects as a single configuration only when the objects were adjacent. Although the findings could be explained in terms of a special predisposition to attend to regions where one object contacts another (see footnote to p. 376), it seems more likely that the findings reflect infants' differential perceptions of object boundaries in the adjacent and separated displays. The findings provide support for the hypothesis that the adjacent objects were perceived as a single unit whose integrity was broken by the displacement of one object, whereas the separated objects were perceived as distinct units.

This same hypothesis is supported by the findings of studies of object-directed reaching (Hofsten & Spelke, 1985), in which 5-month-old infants reached for two objects that were adjacent in depth as a single unit and for two objects that were separated in depth as distinct units. The hypothesis is further supported by the findings of a preliminary experiment using a number-detection method, in which 3-month-old infants treated two adjacent objects as a single countable unit and two objects that were separated in depth as two countable units (Prather & Spelke, 1982; see also Spelke, 1985*b*). Finally, the hypothesis is supported by studies using a surprise method, in which infants reacted with apparent signs of surprise to the differential movement of one of two adjacent objects (see Spelke *et al.*, 1983; Spelke, 1985*b*). Four sets of experiments suggest, therefore, that infants perceive object boundaries by detecting the spatial separation of surfaces, grouping together surfaces that touch in the three-dimensional layout and grouping apart surfaces that are separated in that layout.

Since the infants in the present studies were only 3 months old, these experiments provide evidence against the view that the capacity to perceive objects by detecting three-dimensional surface arrangements develops through the coordination of vision and prehension. According to Piaget (1952) and to many empiricists (e.g. Helmholtz, 1885), the first major milestone linking vision and prehension is provided by the onset of visually guided reaching, at about 4½ months. Our experiments suggest that infants well below this age are already sensitive to the arrangements of surfaces in depth, and that they perceive object boundaries by detecting those arrangements. At least one aspect of the adult's capacity to perceive objects appears to be present and functional before vision becomes coordinated with reaching and manipulation. Although it remains possible that the more limited visual or manual activities shown in the first 3 months of life play a role in the development of object perception, object perception does not seem to develop entirely through a process of coordinating what one sees with what one manipulates.

Object perception and Gestalt organization

The present experiments, like Piaget's observations of reaching for supported objects, provide evidence against the view that infants first perceive objects by organizing visual displays into units that are maximally simple and regular. Although negative conclusions must be made tentatively, the 3-month-old infants in these studies showed no sign of perceiving the boundary between two objects of different colours, textures, sizes, and shapes when the objects were adjacent. Unlike adults, they did not appear to organize displays of adjacent objects in accord with the Gestalt principles of similarity, good continuation, and good form.

The failure to respond to adjacent objects in accord with these Gestalt principles cannot be attributed to a lack of sensitivity to object colours, textures, shapes, and forms; infants of 3 months appear to be sensitive to all these properties (see Banks & Salapatek, 1983, and E. Gibson & Spelke, 1983, for reviews). It seems, rather, that young infants fail to use these properties as information about object boundaries. In this respect, the present findings complement the findings of recent studies of perception of partly occluded objects. Four-month-old infants have been found to perceive a centre-occluded object as a connected unit that continues behind its occluder if the ends of the object are presented in motion (Kellman & Spelke, 1983; Kellman *et al.*, 1986). In contrast to adults (Kellman & Spelke, 1983; Schmidt & Spelke, 1984) and toddlers (Schmidt, 1985), however, infants do not perceive such an object as a connected unit if it is stationary and has a uniform colour and a simple, regular form (Kellman & Spelke, 1983; Schmidt & Spelke, 1984; Schmidt, *et al.*, 1986). Infants appear to detect the colours and forms of the visible surfaces of a centre-occluded object (Kellman & Spelke, 1983; Schmidt & Spelke, 1984), but they do not perceive the continuity of the object over occlusion by analysing those properties. In general, the tendency to perceive objects in accord with Gestalt principles appears to develop after 5 months (see Schmidt, 1985) and after infants have already begun to perceive the unity and the boundaries of objects in other ways: by detecting the spatial arrangements and the movements of surfaces in the three-dimensional layout.

Object perception and knowledge about the physical world

When adults were shown the present displays, their judgements of the objects' connectedness and movability appeared to be influenced by knowledge of the conditions under which a physical object is stably supported. The adults were more apt to judge that the two objects were connected to one another and to predict that the objects would move together when the objects were suspended in the air than when each stood stably on a surface. In contrast, infants appeared not to differentiate between these two support conditions. The present experiments thus provide no evidence that infants perceive object boundaries by analysing the support relations among surfaces. This finding is consistent with Keil's (1979) report that young infants do not use information about the support relations among objects to predict when an object will fall. Both studies suggest, not surprisingly, that object perception in infancy is not guided by all the physical knowledge that guides object perception by adults.

It is possible, nevertheless, that the earliest capacity to perceive object boundaries is guided by physical knowledge of a certain kind. Infants appear to perceive objects by analysing the spatial connections and the movements of surfaces, and this tendency may stem, in part, from an initial notion that the physical world divides into entities that are *cohesive*: entities that are spatially connected and that maintain their connections as they move (Spelke, in press). The infants in the present studies may have dishabituated to the independent displacement of one object in a configuration of two adjacent objects because they expect sets of adjacent surfaces to be cohesive and thus to remain connected over movement.

If this suggestion is correct, then the initial capacity to perceive objects may depend on conceptions of physical bodies and their spatio-temporal properties, much as Piaget (1954) and others have proposed (see Spelke, in press). Such a conception, however, would seem to be present and functional quite early in infancy.

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