ELSEVIER

Cognition 62 (1997) 121–149

COGNITION

Object segregation in 8-month-old infants

Amy Needham[a,*], Renée Baillargeon[b]

[a]*Department of Psychology: Experimental, Duke University, Durham, NC 27708-0086, USA*
[b]*Department of Psychology, University of Illinois, 603 E. Daniel St., Champaign, IL 61820, USA*

Received 9 January 1995, final version 7 May 1996

Abstract

Two experiments examined 8-month-old infants' use of configural and physical knowledge in segregating three-dimensional adjacent displays. The infants in Experiment 1 saw two identical yellow octagons standing side by side; in the test events, a hand grasped the right octagon and pulled it to the side. The infants looked reliably longer when the octagons moved apart than when they moved together, suggesting that the infants (a) perceived the octagons as a single unit and hence (b) expected them to move together and were surprised when they did not. The infants in Experiment 2 saw a yellow cylinder and a blue box; a hand grasped the cylinder and pulled it to the side. The infants looked reliably longer when the box moved with the cylinder than when the box remained in place, suggesting that they (a) viewed the cylinder and box as distinct units and thus (b) expected the cylinder to move alone and were surprised when it did not. These results indicate that, by 8 months of age, infants use configural knowledge when organizing adjacent displays: they expect similar parts to belong to the same unit and dissimilar parts to belong to distinct units. Additional results revealed that 8-month-old infants' interpretation of displays is affected not only by configural but also by physical considerations. Thus, infants in Experiment 1 who saw a thin blade lowered between the octagons viewed them as two rather than as one unit. Similarly, infants in Experiment 2 who saw the cylinder lying above instead of on the apparatus floor perceived the cylinder and box as one rather than two units. These results indicate that 8-month-old infants bring to bear their knowledge of impenetrability and support when parsing adjacent displays. Furthermore, when faced with two conflicting interpretations of a display, one suggested by their configural and one by their physical knowledge, infants allow the latter to supersede the former. Together, these findings suggest that, by 8 months of age, infants' approach to segregation is fundamentally similar to that of adults.

* Corresponding author. Fax: + 1 919 660 5726.

0010-0277/97/$17.00
PII S0010-0277(96)00727-5

1. Introduction

Consider a typical kitchen in the aftermath of a large dinner party, with pots, pans, bowls, dishes, glasses, cooking utensils, and silverware jumbled haphazardly upon every available surface. When surveying (faintheartedly) such a scene, we perceive not tangled contours, not snarled fragments intertwined in a confused mass, but distinct, complete objects. How is the process of object segregation accomplished?

Researchers have long been interested in identifying the various factors involved in adults' carving of three-dimensional scenes into separate units. One such factor, adults' knowledge about objects, has been the subject of considerable debate (e.g., Biederman, 1987; Biederman et al., 1982; Fodor, 1983; Fodor and Pylyshyn, 1981; Gibson, 1979; Granrud et al., 1985; Kanizsa, 1979; Marr, 1982; Michaels and Carello, 1981; Rock, 1975, 1983; Turvey et al., 1981; Ullman, 1980, 1986). At issue is whether what we know about objects affects how we perceive objects. Some researchers believe that perception is not influenced by knowledge (e.g., Fodor, 1983; Gibson, 1979; Kanizsa, 1979; Michaels and Carello, 1981; Turvey et al., 1981). Processing of the information contained in the visual image is deemed by some of these theorists to be unnecessary (e.g., Gibson, 1979), and by others to take place in individual modules that do not exchange information until their functions are complete (e.g., Fodor, 1983). Despite their theoretical differences, investigators within this perspective agree that one's beliefs about the world cannot alter how one perceives the world.

Other researchers argue that the information contained in the visual image is not sufficient to ensure accurate perception and must be augmented with stored knowledge about objects and events (e.g., Biederman, 1987; Biederman et al., 1982; Granrud et al., 1985; Hummel and Biederman, 1992; Kellman and Spelke, 1983; Marr, 1982; Palmer, 1975; Rock, 1983; Shepard, 1983; Spelke, 1988, Spelke, 1990; Ullman, 1980, Ullman, 1986). On this view, there is considerable ''cross-talk'' between lower and higher levels of perceptual and cognitive processing.

Our approach (Needham, in press; Needham and Baillargeon, in press; Needham et al., 1997) shares much in spirit with this second perspective. We believe that at least three kinds of object knowledge contribute to adults' segregation of stationary three-dimensional displays: configural, physical, and experiential knowledge. Each kind of knowledge is briefly discussed below.

Configural knowledge refers to adults' expectations about how objects typically appear: adults recognize that objects are generally regular in shape, pattern, color, texture, and so on. As a result, adults tend to group surfaces with similar perceptual features into the same units, and surfaces with different perceptual features into separate units. Thus, we organize the surfaces on either side of the box in Fig. 1(A) into a single unit, but parse the surfaces in Fig. 1(B) into two adjacent units.

Physical knowledge corresponds to adults' beliefs about the lawful ways in which objects can move and interact, such as the beliefs that objects cannot move through space occupied by other objects and cannot remain stable without support.

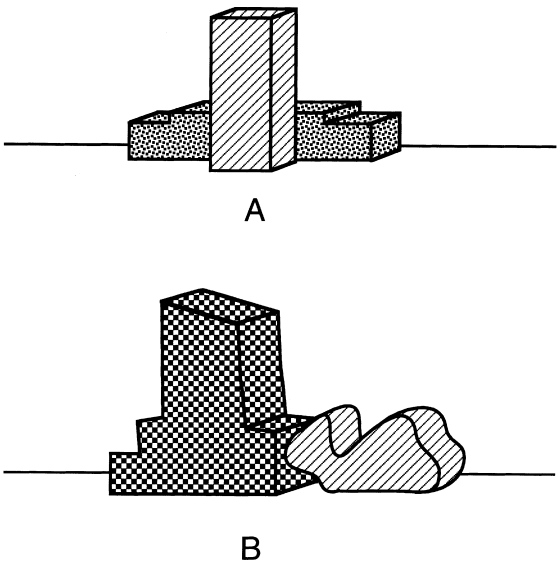

Fig. 1. Based on our configural knowledge, the portion of the display behind the striped box in A would be parsed into a single unit, and the display shown in B would be parsed into two distinct units.

Adults not only rely on their physical knowledge to predict object boundaries in a scene, but, in cases of conflict, typically allow interpretations dictated by this knowledge to override interpretations suggested by their configural knowledge. In Fig. 2(A), for example, the introduction of the barrier behind the box leads us to conclude that the surfaces visible to the left and right of the box cannot belong to the same object because the occluded portion of this object would occupy the same space as the barrier, an impossible feat. Similarly, we immediately infer that the surfaces in Fig. 2(B) cannot belong to two separate units because one of the units would be suspended in midair without support, again an unacceptable outcome.

Experiential knowledge refers to adults' knowledge of what specific objects, or types of objects, exist in the world. This knowledge involves representations of particular objects (e.g., our toothbrush, key ring, or computer) as well as more abstract representations of object categories (e.g., pens, hammers, and chairs). As with their physical knowledge, adults commonly allow interpretations suggested by their experiential knowledge to supersede contrary interpretations suggested by their configural knowledge (but see Michotte et al., 1964). To illustrate, we assume that the surfaces to the left and right of the box in Fig. 3 belong to a single object because this object, although novel, resembles familiar household implements.

2. Object segregation in infancy

The previous discussion raises several questions about the development of

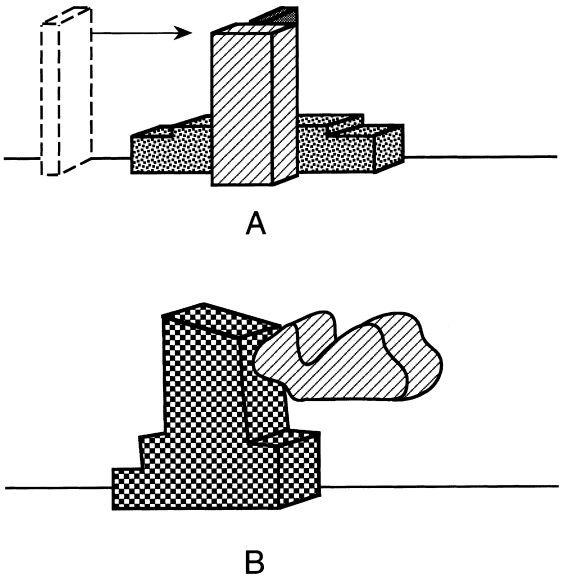

Fig. 2. Based on our knowledge of the physical world, we would revise our interpretation of these two novel displays. What was grouped into a single unit (A) based on configural information is seen as two separate units as a result of information about impenetrability. Similarly, what was grouped into two units (B) on the basis of configural information is seen as a single unit as a result of information about support.

object segregation in infancy. In particular, at what age do infants begin to use each of the three kinds of object knowledge – configural, physical, and experiential – described above to segregate displays? And how do infants come to integrate the sometimes conflicting interpretations suggested by the different kinds of knowledge to attain a stable, veridical view of objects in the world?

The present research focuses on infants' use of configural and physical knowledge in segregating stationary three-dimensional displays. Although the role of physical knowledge in this context has been largely ignored, the same is not true of configural knowledge: a large number of experiments, conducted primarily by Spelke, Kellman, and their colleagues, have examined infants' sensitivity to

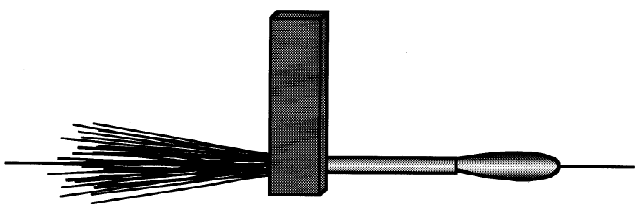

Fig. 3. We see this novel display as composed of a single object behind the screen based on our previous experiences with household items.

featural information in organizing stationary three-dimensional displays (see Kellman and Shipley, 1991; Needham et al., 1997; and Spelke and Van de Walle, 1993, for recent reviews). The results of these investigations typically suggest that young infants do not segregate displays in accordance with their featural properties – grouping together similar but not dissimilar surfaces – and hence do not possess the same configural expectations as adults.[1]

Some of this evidence comes from experiments on infants' perception of *partly occluded* displays (e.g., Craton, 1993, Craton, 1996; Kellman and Spelke, 1983; Schmidt and Spelke, 1984; Schmidt et al., 1986; Termine et al., 1987). In one experiment, for example, Kellman and Spelke (1983) habituated 4-month-old infants to a stationary rod whose center was occluded by a block. Following habituation, the block was removed and the infants were shown two test displays: a complete rod, and an incomplete rod composed of the two rod segments visible above and below the block in habituation. The infants tended to look equally at the two test displays. These and control results indicated that the infants were uncertain whether the rod segments visible in the habituation display belonged to a single object. The same ambiguous percept was observed in subsequent experiments in which the rod was replaced with a triangular rod figure (Kellman and Spelke, 1983), a two-dimensional surface (Termine et al., 1987), a cube or sphere (e.g., Schmidt and Spelke, 1984), or, in experiments with 5-month-old infants, a nonsense form (Schmidt et al., 1986), a two-dimensional surface (Craton, 1996), and a box with jagged edges (Craton, 1993). Together, these results suggest that infants aged 5 months and younger do not attend to featural information when organizing partly occluded displays.

Investigations of infants' perception of *adjacent* displays have yielded similar results (e.g., Hofsten and Spelke, 1985; Kestenbaum et al., 1987; Piaget, 1954; Spelke, 1988; Spelke et al., 1989; Spelke et al., 1993). For example, Spelke et al. (1993) habituated 5-month-old infants to a bell-shaped display made of thin concentric rings of foam core that were painted a uniform color and decorated with metallic stars. Following habituation, the infants saw two test events: a move-together and a move-apart event. In both events, a hand grasped the top of the display and lifted it into the air. In the move-together event, the display moved as a whole. In the move-apart event, only the top half of the display moved; the bottom half remained stationary on the apparatus floor. The infants tended to look equally at the move-together and the move-apart events, suggesting that they were uncertain whether the bell-shaped display was composed of one or more objects. The findings obtained with partly occluded and adjacent displays are thus

[1] A few findings in the segregation literature point to a different, less negative characterization of young infants' sensitivity to featural information. First, when tested with two- as opposed to three-dimensional displays, infants as young as 3 months of age attend to featural information (e.g., Atkinson and Braddick, 1992; Bornstein and Krinsky, 1985; Colombo et al., 1984; Ghim, 1990; Ghim and Eimas, 1988; Giffen and Haith, 1984; Milewski, 1979; Salapatek, 1975; Treiber and Wilcox, 1980). Second, new experiments by Needham (in press) that build on the present research suggest that 4.5-month-old infants are able to organize at least some three-dimensional displays in accordance with their featural properties. We return to these last findings in the Conclusion section.

consistent in suggesting that infants aged 5 months or younger do not segregate displays in accordance with their featural properties.

At what age do infants begin to demonstrate configural knowledge? Findings obtained by Schmidt et al. (1986) provide a tentative answer to this question. In their experiment, 7-month-old infants were habituated to a stationary nonsense form whose center was occluded by a narrow screen. In one condition, the surfaces visible on either side of the screen were non-planar, misaligned, and different in color; in another condition, the surfaces were co-planar, aligned, and uniform in color. Following habituation, the screen was removed, and the infants saw complete and incomplete versions of the habituation displays. The infants in the first condition tended to look equally at the two test displays, suggesting that their perception of the habituation display was indeterminate. In contrast, the infants in the second condition looked reliably longer at the incomplete than at the complete test display, suggesting that they viewed the surfaces on either side of the screen in the habituation display as belonging to a single object. This last result provides evidence that 7-month-old infants are able to organize at least some displays in accordance with their perceptual features.

3. The present research

The goal of the present research was two-fold. First, it sought further evidence that infants in the second half of the first year attend to and use featural information when segregating stationary three-dimensional displays. The experiments examined 8-month-old infants' perception of adjacent displays composed of two parts that were either identical (Experiment 1) or very different (Experiment 2) in appearance. We reasoned that evidence that the infants grouped the similar parts into one unit and the dissimilar parts into separate units would provide a strong indication that 8-month-old infants, like adults, use configural knowledge in parsing displays.

The second goal of the research was to determine whether 8-month-old infants, like adults, bring to bear their physical knowledge when organizing stationary three-dimensional displays. The experiments explored how infants' responses to displays were affected by physical information about impenetrability (Experiment 1) or support (Experiment 2) that conflicted with the interpretations suggested by the displays' perceptual features.

How sensitive are infants to these physical constraints? There is considerable evidence that even young infants possess intuitions about objects' impenetrability (e.g., Baillargeon, 1987, Baillargeon, 1991; Baillargeon and DeVos, 1991; Spelke et al., 1992). For example, Baillargeon (1987) habituated 4.5-month-old infants to a screen that rotated back and forth through a 180° arc. Following habituation, a box was placed behind the screen, and the infants were shown a possible and an impossible event. In the possible event, the screen stopped when it reached the occluded box; in the impossible event, the screen rotated through a full 180° arc, as though the box were no longer present. The infants looked reliably longer at the

impossible than at the possible event. These and control results indicated that the infants (a) understood that the screen could not rotate through the space occupied by the box and hence (b) were surprised in the impossible event when the screen failed to stop against the box.

Recent evidence indicates that young infants also possess intuitions about support (e.g., Baillargeon et al., 1992; Baillargeon et al., 1996; Needham and Baillargeon, 1993). One series of experiments is especially relevant to the present research (Baillargeon et al., 1996). These experiments examined whether 4.5- and 5.5-month-old infants realize that objects are unstable when released against vertical surfaces. The infants saw a possible and an impossible event in which a gloved hand placed a small box against the center of a vertical surface and then released it. Beneath the box was a platform; the only difference between the two test events had to do with the height of the platform. In the possible event, the platform was tall enough to support the box. In the impossible event, the platform was much shorter and did not contact the box; the box simply lay against the vertical surface, well above the platform. The 5.5- and even some of the 4.5-month-old infants looked reliably longer at the impossible than at the possible event. These and control results indicated that the infants (a) recognized that the box could not remain stable when released against the vertical surface above the short platform and thus (b) were surprised in the impossible event that the box did not fall.

In light of the above findings, it seemed reasonable to ask whether 8-month-old infants would bring to bear their intuitions about impenetrability (Experiment 1) and support (Experiment 2) when organizing displays. Positive results would provide the first empirical demonstration that infants, like adults, use their physical knowledge to segregate stationary three-dimensional displays.

EXPERIMENT 1

Experiment 1 addressed two questions. First, would infants organize a three-dimensional adjacent display composed of two identical parts in a manner consistent with its perceptual features? Second, would infants bring to bear their knowledge of impenetrability when segregating the display? To test infants' perception of the display, we used a method similar to that of Spelke et al. (1993). In this method, infants first observe a stationary display to form an interpretation of its composition. Next, infants watch test events in which the entire display moves (move-together event) or only a part of the display moves (move-apart event). The rationale is that if infants perceived the stationary display as a single unit, they should expect it to move as a whole and be surprised when it does not. Conversely, if infants viewed the stationary display as composed of more than one unit, they should expect the units to move independently and be surprised when they do not. Because infants' surprise at an event typically manifests itself by prolonged attention to the event (e.g., Bornstein, 1985; Spelke, 1985), infants are expected to look reliably longer at whichever test event depicts the motion inconsistent with their interpretation of the stationary display.

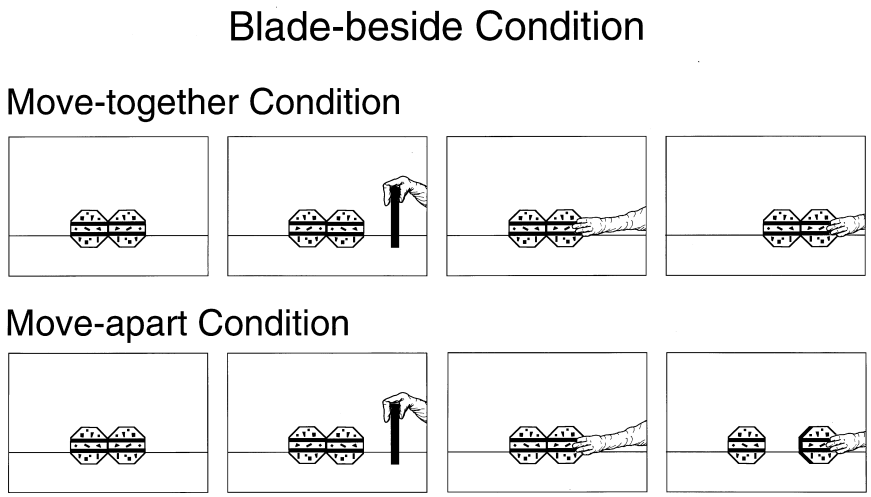

Fig. 4. Schematic drawing of the events shown to the infants in Experiment 1.

The infants in Experiment 1 first received a familiarization trial in which they saw a stationary adjacent display consisting of two yellow octagons decorated with blue dots and stripes (see Fig. 4 Fig. 5). Next, the infants received two test trials. At the start of each test trial, a large, thin, metallic blade encased in a wooden frame stood to the right of the octagons. A gloved hand lifted the blade, turned it 90° (so that only its wooden frame was visible), and lifted and lowered it repeatedly either to the side of the octagons (blade-beside condition) or between the octagons (blade-between condition). Next, the hand removed the blade from

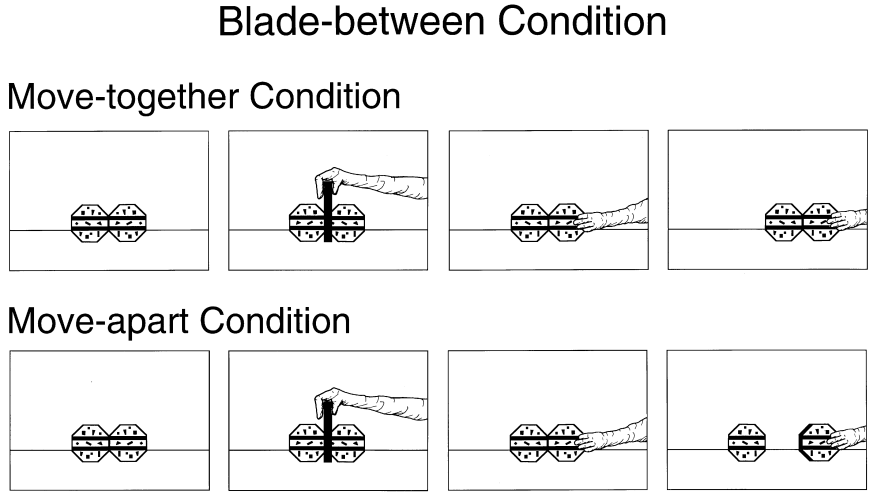

Fig. 5. Schematic drawing of the events shown to the infants in Experiment 1.

the apparatus. Upon reentering the apparatus, the hand took hold of the right octagon and pulled it a short distance to the right. For half of the infants in each blade condition, the left octagon moved with the right octagon when it was pulled (move-together condition). For the other infants, the right octagon moved apart from the left octagon, which remained stationary (move-apart condition). The two blade positions and the two motion conditions were thus crossed to form four separate experimental conditions.[2]

We reasoned that if the infants in the blade-beside condition were led by the perceptual similarity of the two octagons to view them as a single unit, then they should expect the octagons to move together and be surprised when they did not. The infants who saw only the right octagon move should thus look reliably longer than the infants who saw both octagons move.

In addition, if the infants in the blade-between condition (a) reasoned that, because the blade could be inserted between the octagons, the two could not constitute a single unit, and (b) attached more importance to the interpretation suggested by their knowledge of impenetrability (two units) than to the interpretation suggested by the octagons' perceptual features (one unit), then they should expect the octagons to move as separate units and be surprised when they did not. The infants who saw the two octagons move together should therefore look reliably longer than the infants who saw the right octagon move alone.

4. Method

4.1. Subjects

Subjects were 24 healthy, full-term infants ranging in age from 7 months, 23 days to 9 months, 0 days ($M = 8$ months, 7 days). The infants' names in this experiment and in the next experiment were obtained from birth announcements published in the local newspaper. Parents were contacted by letters and follow-up phone calls. They were offered reimbursement for their travel expenses but were not compensated for their participation.

[2] The present method differed in a number of subtle ways from that used by Spelke et al. (1993): the two parts of the adjacent display were placed side by side rather than one on top of the other, the parts were moved to the side rather than upward, and so on. Though these differences were very likely inconsequential, one difference may be worthy of comment. As is common in this literature (e.g., Kellman and Spelke, 1983), Spelke et al. used a within-subjects design in their experiment, showing infants the move-apart and move-together events on alternating trials. In the present research, however, we opted for a between-subjects design because we were concerned about the risk of contamination effects with repeated, alternating trials. Consider, for example, an infant in the blade-beside condition who saw the move-apart event first and the move-together event second. It seemed possible that the infant (a) might show surprise at the first event because it depicted a motion inconsistent with her interpretation of the familiarization display (one unit) and (b) might also show surprise at the second event because it contradicted the interpretation suggested by the first event (two units). Because such contamination effects, if they obtained, would tend to mask differences in infants' responses to the events, subjects in the present research were shown only one test event across trials.

One-quarter of the infants were randomly assigned to each of the four experimental groups formed by crossing the two blade positions and the two motion conditions: blade-beside/move-together condition ($M = 8$ months, 9 days), blade-beside/move-apart condition ($M = 8$ months, 7 days), blade-between/move-together condition ($M = 8$ months, 9 days), and blade-between/move-apart condition ($M = 8$ months, 5 days).

4.2. Apparatus

The apparatus consisted of a wooden cubicle 210 cm high, 102.5 cm wide, and 45.5 cm deep. The infant faced an opening 56 cm high and 95 wide in the front of the apparatus. The floor of the apparatus was covered with dark purple cardboard, the back wall was covered with gray contact paper, and the side walls were painted white.

At the start of each test event, two octagons stood side by side on the floor of the apparatus, 19 cm from the front edge and 31.5 cm from the right wall. Each octagon was 16.5 cm high, 16.5 cm wide, and 10 cm deep, and had regular 7 cm sides. Together, the octagons subtended about 28° (horizontal) and 14° (vertical) of visual angle from the infant's viewpoint. Each octagon was made of yellow cardboard and was decorated with blue dots and with two blue horizontal stripes 2 cm high placed 2 cm apart.

To ensure an even contact between the octagons in their starting positions, a magnet was affixed to the left octagon's interior right side and a metal plate to the right octagon's interior left side. In the move-apart condition, a heavy weight was inserted in the left octagon to prevent its moving with the right octagon when the latter was pulled. In the move-together condition, hidden clips were used to fasten the octagons together and thus prevent their breaking apart when the right octagon was pulled.

In addition to the octagons, a blade was present in the apparatus at the beginning of each test event. This blade consisted of a metal plate 27.5 cm high, 17 cm wide, and 0.5 cm thick, encased on the top and sides in a red wooden frame 2.5 cm high and 4 cm deep. When pressure was applied to the bottom of the blade, a center panel slid smoothly upward, creating a large gap. Thus, although the blade appeared to pass between the octagons in the blade-between condition, it in fact merely slid upward, much like a magician's knife that collapses within itself instead of piercing its ''victim''. The blade's design ensured that the octagons remained motionless when the blade was lowered between them (even slight motions might have provided the infants with useful common fate information; e.g., Kellman et al., 1987; Kellman and Spelke, 1983; Kellman et al., 1986; Slater et al., 1990).

The test objects were manipulated by an experimenter who wore a white spandex glove 59 cm long on her left hand and arm. The hand entered the apparatus through an opening 51 cm high and 24 cm wide in the right wall. This opening was partially covered by a white muslin curtain.

The infants were tested in a brightly lit room. Four clip-on lights (each with a 40

W light bulb) were attached to the back and side walls of the apparatus to provide additional light. Two wooden frames, each 183 cm high and 71 cm wide and covered with black cloth, stood at an angle on either side of the apparatus. These frames served to isolate the infants from the experimental room. At the end of each trial, a curtain consisting of a muslin-covered frame 60 cm high and 101 cm wide was lowered in front of the opening in the front wall of the apparatus.

4.3. Events

The numbers in parentheses indicate the number of seconds needed to perform the actions described. To help the experimenter adhere to the events' scripts, a metronome beat softly once per second.

4.3.1. Blade-between/move-together event

Each test trial was preceded by a pretrial in which the blade was manipulated. At the start of the pretrial, the blade faced the infant, 5 cm from the right wall of the apparatus and 5 cm behind the right octagon; the experimenter's gloved hand held the top of the blade's wooden frame. The hand lifted the blade from above and rotated it 90° (1 s) so that it stood parallel to the infant's line of sight; in this position, only the blade's wooden frame was visible. Next, the hand lowered the blade between the octagons and lightly tapped the apparatus floor once per second. After the computer signaled that the infant had accumulated 6 s of looking at the blade, the hand removed it from the apparatus through the opening in the right wall (2 s). The hand immediately re-entered the apparatus (1 s), to begin the test trial proper. The hand first paused (1 s) on the floor, about half-way between the right octagon and the opening in the right wall. Next, the hand grasped the right octagon (1 s) and pulled it 16 cm to the right at the approximate rate of 8 cm/s (2 s). The left octagon moved with the right octagon, sliding smoothly over the apparatus floor. After a 1 s pause, the hand pushed the octagons back to their starting positions (2 s). The hand then returned to its resting position on the apparatus floor (1 s), paused for 1 s, and again grasped the right octagon, beginning a new event cycle. Cycles were repeated without stop until the computer signaled that the trial had ended (see below). When this occurred, a second experimenter lowered the curtain in front of the apparatus.

4.3.2. Blade-between/move-apart event

The test event shown to the infants in the blade-between/move-apart condition was identical to that shown to the infants in the blade-between/move-together condition except that only the right octagon moved: the left octagon remained stationary throughout the event.

4.3.3. Blade-beside/move-together event and blade-beside/move-apart event

The test events shown to the infants in the blade-beside/move-together and move-apart conditions were identical to those shown to the infants in the blade-between/move-together and move-apart conditions, respectively, with one excep-

tion. At the start of each test trial, the hand lowered the blade 16 cm to the right of the octagons instead of between them.

4.4. Procedure

During the experiment, each infant sat on his or her parent's lap in front of the apparatus. The infant's head was approximately 65 cm from the octagons. The parent was asked not to interact with the infant while the experiment was in progress. The parent was also instructed to close his or her eyes during the test trials.

The infant's looking behavior was monitored by two observers who viewed the infant through peepholes in the cloth-covered frames on either side of the apparatus. The observers were not told and could not determine whether the infants were assigned to the move-together or the move-apart condition.[3] Each observer held a button box connected to a Dell microcomputer and depressed the button when the infant attended to the events. Each trial was divided into 100 ms intervals, and the computer determined in each interval whether the two observers agreed on the direction of the infant's gaze. Inter-observer agreement was calculated for each trial on the basis of the number of intervals in which the computer registered agreement, out of the total number of intervals in the trial. Agreement in this experiment and in the next experiment averaged 92% or more per trial per infant. The looking times recorded by the primary observer were used to determine the end of the trials.

The infants first received a familiarization trial. The purpose of this trial was to give the infants the opportunity to inspect the experimental display and form an interpretation of its composition. During the trial, the octagons stood stationary in the apparatus; neither the experimenter's hand nor the blade was present so as to not distract the infants. The trial ended when the infants either (a) looked away from the display for 2 consecutive seconds after having looked at it for at least 10 cumulative seconds or (b) looked at the display for 30 cumulative seconds without looking away for 2 consecutive seconds. Analysis of the looking times of the infants in the four experimental conditions during the familiarization trial revealed no reliable differences, $F(1, 20) = 0.16$ (blade-beside/move-together condition, $M = 15.0$, $SD = 7.1$; blade-beside/move-apart condition, $M = 15.8$, $SD = 7.4$; blade-between/move-together condition, $M = 16.0$, $SD = 4.8$; and blade-between/move-apart condition, $M = 19.1$, $SD = 7.7$).

Following the familiarization trial, the infants saw the test event appropriate for their condition, as described above, on two successive trials. Each test trial ended

[3] The observers could determine whether the infants were in the blade-beside or the blade-between condition by the direction of their gaze during the pretrial preceding each test trial. The infants' gaze did not reveal, however, whether they were watching the move-apart or the move-together event during the test trials. For each infant, the primary observer (whose input was used to end the trials) was asked to guess, after the final test trial, which of the two test events the infant had seen. The primary observer guessed correctly for only 13 of the 24 infants in the experiment, a chance performance.

when the infants either (a) looked away from the event for 2 consecutive seconds after having looked at it for at least 8 cumulative seconds (beginning at the end of the pretrial, when the hand removed the blade from the apparatus) or (b) looked at the event for 60 cumulative seconds without looking away for 2 consecutive seconds. The 8 s value was chosen to ensure that the infants had sufficient information to distinguish between the move-apart and the move-together events.

Preliminary analyses revealed no reliable effect of sex on the infants' total looking times at the move-apart and the move-together events (all Fs < 0.77). The data were therefore collapsed in subsequent analyses.

5. Results

Fig. 6 presents the mean total looking times of the infants in the four experimental conditions. It can be seen that the infants in the blade-beside condition looked longer when the octagons moved apart than when they moved together, whereas the infants in the blade-between condition showed the opposite looking pattern.

The infants' looking times were summed across the two test trials and compared by means of a 2×2 analysis of variance (ANOVA), with Blade Position Condition (blade-beside or blade-between) and Motion Condition (move-together or move-apart) as between-subjects factors. There was a significant Blade Position Condition $\times$ Motion Condition interaction, $F(1, 20) = 12.37$, $p < .0025$. Planned comparisons indicated that the infants in the blade-beside condition looked reliably longer when the octagons moved apart ($M = 110.5$, $SD = 13.8$) than when they

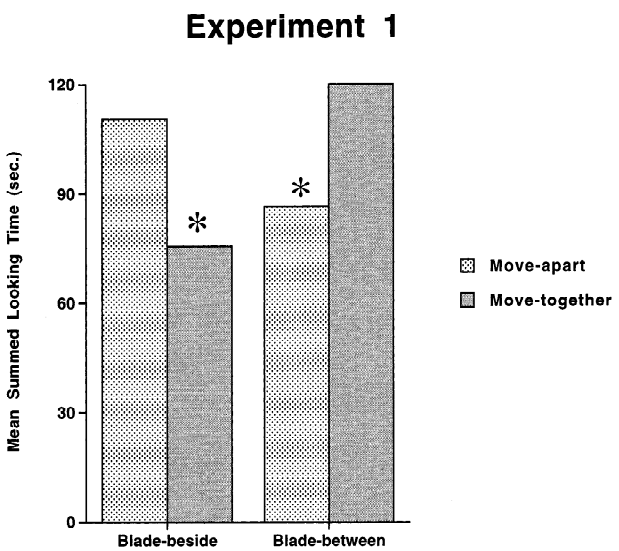

Fig. 6. Infants' mean looking times at the four test events in Experiment 1.

moved together ($M = 75.5$, $SD = 29.3$), $F(1, 20) = 6.44$, $p < .025$; in contrast, the infants in the blade-between condition looked reliably longer when the octagons moved together ($M = 120.0$, $SD = 0$) than when they moved apart ($M = 86.4$, $SD = 35.1$), $F(1, 20) = 5.93$, $p < .025$. No other effects were significant.

Because across conditions many infants looked the maximum number of seconds allowed per trial (60 s) on both test trials, there was reason to doubt whether an ANOVA was the appropriate way to analyze the present data. In the blade-between/move-together condition, all 6 of the infants looked the maximum total of 120 s on the test trials; the corresponding numbers for the other three conditions were: blade-between/move-apart, 2 infants; blade-beside/move-together, 1 infant; and blade-beside/move-apart, 3 infants. These results are interesting in themselves, because they suggest that it was primarily the infants who saw motions inconsistent with their physical (blade-between/move-together) or configural (blade-beside/move-apart) beliefs that looked the maximum amount of time allowed: whereas 9 of the 12 infants in these two ''surprising'' conditions looked 120 s, only 3 of the 12 infants in the non-surprising conditions (blade-between/move-apart and blade-beside/move-together) did so, a difference that is significant by a Fisher test ($p < .025$).

To address the concerns raised by the presence of censored observations in the data (i.e., the infants who looked at the test displays for the maximum amount of time allowed), a final set of analyses was carried out using survival analysis techniques designed to accommodate censored data (Lee, 1992). The survival analyses compared the empirical survival distributions (i.e., the estimated probabilities that the infants were still looking at each second within a test trial) of the move-together and move-apart infants in each blade position condition. The survival distributions were estimated using the product-limit method in the BMDP 1L program (Dixon, 1992); trial was included as a stratification variable. The results were similar to those of the ANOVA, as determined by the Peto–Prentice version of the Generalized Wilcoxon (W) statistic, which is asymptotically distributed as χ^2_1. In the blade-beside condition, the infants who saw the move-apart event looked reliably longer than the infants who saw the move-together event, $W(1) = 5.75$, $p < .025$. The effect was reversed for the screen-between condition, with the infants who saw the move-together event looking reliably longer than the infants who saw the move-apart event, $W(1) = 8.91$, $p < .005$.

6. Discussion

The infants in the blade-beside condition looked reliably longer when only the right octagon moved than when both the right and the left octagons moved; the infants in the blade-between condition showed the opposite looking pattern. Together, these results suggest that the infants in the blade-beside condition perceived the octagons as *one* cohesive unit and hence expected them to move together and were surprised when this expectation was violated. In contrast, the infants in the blade-between condition viewed the octagons as *two* separate units

and thus expected them to move independently and were surprised when they did not.

The findings of Experiment 1 point to three conclusions. The first is that 8-month-old infants are able to use configural knowledge to organize stationary adjacent displays. The results of the blade-beside condition suggest that the infants were led by the highly similar features of the two octagons to group them into a single unit. The second conclusion is that 8-month-old infants can use their intuitions about impenetrability to segregate adjacent displays. The results of the blade-between condition suggest that the infants perceived the octagons as two distinct units because they realized, after seeing the blade inserted between the octagons, that the two could not be attached. Finally, the third conclusion is that, when faced with two conflicting interpretations of a display, one suggested by their configural and one by their physical knowledge, 8-month-old infants allow the latter to override the former. After the blade was removed from the apparatus, the infants in the blade-between condition saw the same display as the infants in the blade-beside condition and thus were exposed to the same featural information; nevertheless, the infants in the blade-between condition judged that the octagons constituted two rather than one unit.

EXPERIMENT 2

Experiment 2 was designed to confirm and extend the results of Experiment 1. Two questions were addressed. First, would 8-month-old infants organize a three-dimensional adjacent display composed of two highly dissimilar (as opposed to two identical) parts in accordance with its perceptual features? Second, would infants bring to bear their knowledge of support (rather than impenetrability) when segregating the display?

The infants in Experiment 2 first received a familiarization trial in which they saw a stationary adjacent display consisting of a yellow, zigzag-edged cylinder on the left, and a blue, rectangular box on the right (see Fig. 7 Fig. 8). For half of the infants (cylinder-down condition), the cylinder rested on the floor of the apparatus and made contact with the lower portion of the box. For the other infants (cylinder-up condition), the cylinder was suspended above the apparatus floor and made contact with the upper portion of the box. Following the familiarization trial, the infants received four test trials in which they saw a gloved hand grasp the cylinder and pull it a short distance to the left. For half of the infants in each cylinder position condition, the cylinder and box moved together as one unit (move-together condition). For the other infants, the cylinder moved apart form the box, which remained stationary (move-apart condition). The two cylinder position and the two motion conditions were thus crossed to form four separate experimental conditions.

We reasoned that if the infants in the cylinder-down condition were led by the different features of the cylinder and box to perceive them as separate units, then they should expect the box to remain stationary when the cylinder moved and be surprised when this expectation was violated. The infants in the move-together

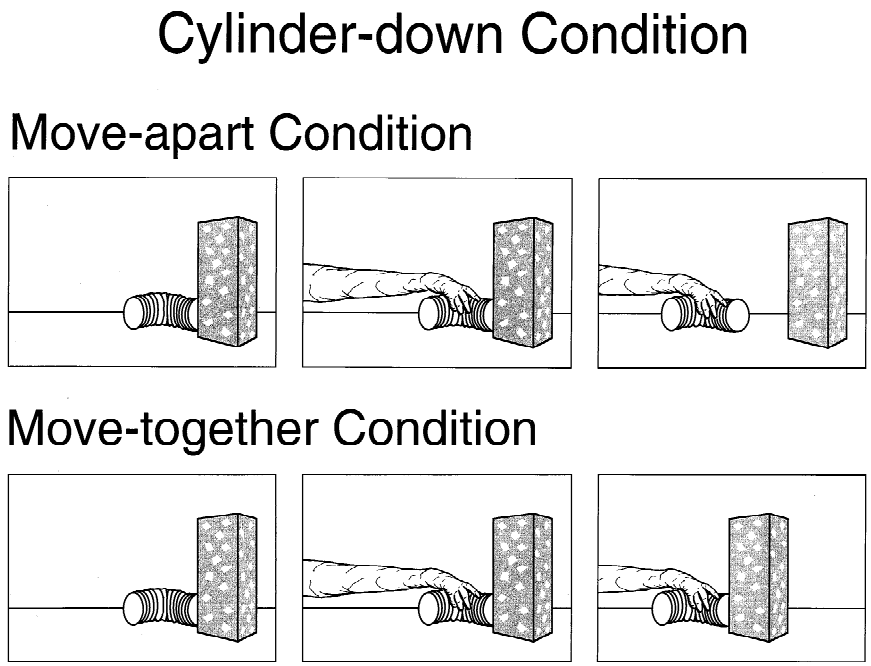

Fig. 7. Schematic drawing of the events shown to the infants in Experiment 2.

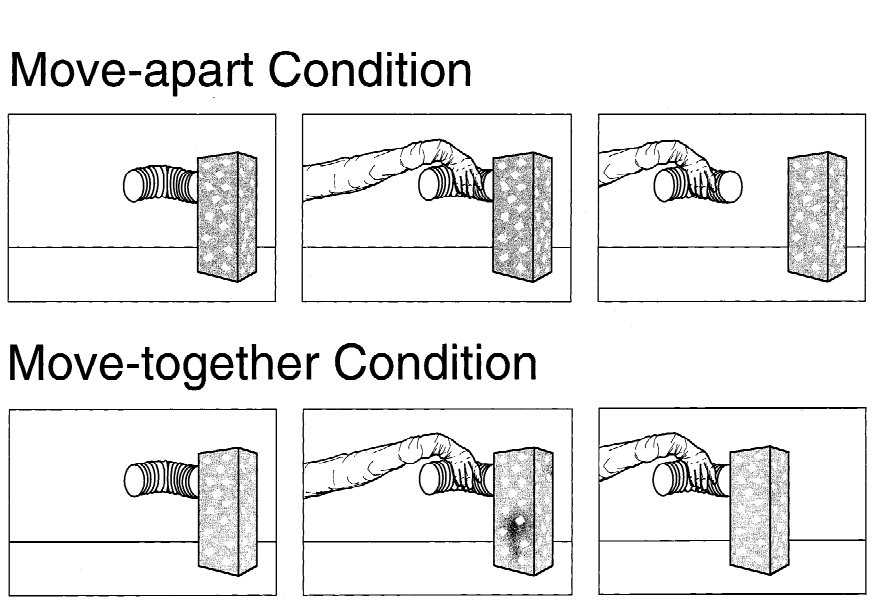

Fig. 8. Schematic drawing of the events shown to the infants in Experiment 2.

condition should therefore look reliably longer than the infants in the move-apart condition.

In addition, if the infants in the cylinder-up condition (a) reasoned that, because the box provided the cylinder's only visible means of support, the two must be attached and (b) allowed the interpretation dictated by support to supersede that suggested by the display's perceptual features, then they should expect the cylinder and box to move as a single unit and be surprised when they did not. The infants in the move-apart condition should thus look reliably longer than the infants in the move-together condition.

7. Method

7.1. Subjects

Subjects were 24 healthy, full-term infants ranging in age from 7 months, 17 days to 7 months, 29 days ($M = 7$ months, 23 days). One-quarter of the infants were randomly assigned to each of the four experimental conditions: cylinder-down/move-together ($M = 7$ months, 27 days), cylinder-down/move-apart ($M = 7$ months, 21 days), cylinder-up/move-together ($M = 7$ months, 24 days), and cylinder-up/move-apart ($M = 7$ months, 19 days).

7.2. Apparatus

The apparatus consisted of a wooden cubicle 182 cm high, 103 cm wide, and 45 cm deep. The infant faced an opening 40 cm high and 93 cm wide in the front wall of the apparatus. The floor of the apparatus was covered with pale blue cardboard and the back and side walls were covered with brightly lined white contact paper. The back wall presented a horizontal slit 3 cm high and 100 cm wide that was partly concealed by a ribbon of white fringe 5 cm high affixed to the wall immediately above the slit. The slit was located 22 cm above the apparatus floor.

The experimental display shown to the infants in the cylinder-down condition was composed of a zigzag-edged cylinder and a rectangular box placed side by side on the apparatus floor. The cylinder was 22 cm long and 10 cm in diameter. It consisted of a rigid section of clothes dryer vent hose that was stuffed and had its ends curved slightly forward. The left end of the cylinder was covered with cardboard; the right end was covered with a thin metal disk. The entire cylinder was painted bright yellow. The box was 32.5 cm high, 12 cm wide, and 12 cm deep. It was made of thick cardboard and was covered with bright blue contact paper decorated with small white squares. One of the box's corners faced the infants. The left rear wall of the box (not visible to the infants) had two magnet insets, one 3.5 cm from the bottom and one 9.5 cm from the top. The cylinder lay on the apparatus floor with its right, metallic end set against the box's bottom magnet (this design ensured an even contact between the cylinder and the box in their starting positions; it also ensured that the box moved with the cylinder in the

move-together event). To help make clear to the infants that the cylinder and box were adjacent, the front 2.5 cm of the cylinder's right end protruded from the box's left corner. The box was 17.5 cm from the front edge of the apparatus and 30 cm from the right wall; the cylinder was 20 cm from the front edge of the apparatus and 33 cm from the left wall. Together, the cylinder and box subtended about 29° (horizontal) and 27° (vertical) of visual angle from the infants' viewpoint.

The experimental display shown to the infants in the cylinder-up condition was similar to that shown to the infants in the cylinder-down condition with one exception: the cylinder was suspended 16 cm above the floor of the apparatus, with its right, metallic end set against the box's top magnet. The cylinder was held in place (out of the infants' view) by means of two clips attached to a metal rod 1 cm in diameter and 53.5 cm long. This rod protruded through the slit in the back wall of the apparatus. Behind the back wall, the rod was encased in a metal plate 8 cm high, 5.5 cm wide, and 2 cm deep. This plate was mounted via linear ball bearings on two metal shafts, each 1 cm in diameter and 91.5 cm long. The two shafts lay parallel, one 7 cm above the other, forming a horizontal track (the shafts' endpoints were attached to a metal frame). When the experimenter pulled the cylinder, the rod and plate slid smoothly and easily along the track.

To produce the move-apart event shown to the infants in the cylinder-down and cylinder-up conditions, a cardboard cover was placed over the box's magnets and a heavy weight was inserted in the box; these changes ensured that the box remained in place when the cylinder was pulled.

In each test event, the cylinder was pulled by an experimenter's right hand wearing a bright silver spandex glove 59 cm long. The hand entered the apparatus through an opening 22 cm high and 18 cm wide in the left wall. This opening was partially hidden by a white muslin curtain.

The infants were tested in a brightly lit room. Four clip-on lights (each with a 40 W light bulb) were attached to the back and side walls of the apparatus to provide additional light. Two wooden frames, each 182 cm high and 71 cm wide and covered with blue cloth, stood at an angle on either side of the apparatus. These frames served to isolate the infants from the experimental room. At the end of each trial, a curtain consisting of a muslin-covered frame 100 cm high and 60 cm wide was lowered in front of the opening in the front wall of the apparatus.

7.3. Events

7.3.1. Cylinder-down/move-together condition

At the start of each test trial, the experimenter's right hand rested on the apparatus floor about half-way between the cylinder and the opening in the left wall. After a 1 s pause, the hand grasped the cylinder (1 s) and pulled it 14 cm to the left at the approximate rate of 7 cm/s (2 s). The box moved with the cylinder, its cardboard bottom sliding smoothly over the apparatus floor. The hand paused

for 1 s and then pushed the cylinder and the box back to their starting positions (2 s). The hand then resumed its initial position on the apparatus floor (1 s). Each event cycle thus lasted about 8 s. Cycles were repeated without stop until the computer signaled that the trial had ended (see below). When this occurred, a second experimenter lowered the curtain in front of the apparatus.

7.3.2. Cylinder-down/move-apart condition

The test event shown to the infants in the cylinder-down/move-apart condition was identical to that shown to the infants in the cylinder-down/move-together condition except that only the cylinder moved: the box remained stationary throughout the trial.

7.3.3. Cylinder-up/move-together and cylinder-up/move-apart conditions

The test events shown to the infants in the two cylinder-up conditions were identical to those shown to the infants in the corresponding cylinder-down conditions except that the cylinder was now suspended above the apparatus floor.

7.4. Procedure

During the experiment, each infant sat on his or her parent's lap in front of the apparatus. The infant's head was approximately 65 cm from the box.

The infants first received a familiarization trial. As in Experiment 1, this trial was intended to give the infants the opportunity to observe the experimental display and form an interpretation of its composition. For the infants in the cylinder-down condition, the cylinder lay on the apparatus floor next to the box; for the infants in the cylinder-up condition, the cylinder was suspended above the apparatus floor next to the box. The experimenter's hand did not enter the apparatus during the trial so as to not distract the infants. The trial ended when the infants either (a) looked away from the display for 2 consecutive seconds after having looked at it for at least 10 cumulative seconds or (b) looked at the display for 30 cumulative seconds without looking away for 2 consecutive seconds. No reliable difference was found between the looking times during the familiarization trial of the infants in the four experimental conditions, $F(1, 20) = 1.85$, $p > .10$ (cylinder-down/move-together, $M = 11.3$, $SD = 0.8$; cylinder-down/move-apart, $M = 15.9$, $SD = 4.5$; cylinder-up/move-together, $M = 15.3$, $SD = 7.4$; and cylinder-up/move-apart, $M = 14.3$, $SD = 5.1$).

Following the familiarization trial, the infants saw the test event appropriate for their condition, as described above, on four successive trials (one advantage of giving the infants four as opposed to two test trials, as in Experiment 1, was that it decreased the likelihood that the infants would look the maximum number of seconds allowed across all trials). Each test trial ended when the infants either (a) looked away from the event for 2 consecutive seconds after having looked at it for

at least 8 cumulative seconds or (b) looked at the event for 60 cumulative seconds without looking away for 2 consecutive seconds.[4]

Preliminary analyses revealed no reliable effect of sex on the infants' total looking times at the test events (all Fs < 3.90, $p > .05$). The data were therefore collapsed in subsequent analyses.

8. Results

Fig. 9 presents the mean total looking times of the infants in the four experimental conditions. It can be seen that the infants in the cylinder-down condition looked longer overall when the cylinder and box moved together than when the cylinder moved alone. The infants in the cylinder-up condition, in contrast, showed the opposite looking pattern.

The infants' looking times were summed across the four test trials and compared by means of a 2×2 ANOVA with Cylinder Position Condition (cylinder-down or cylinder-up) and Motion Condition (move-together or move-

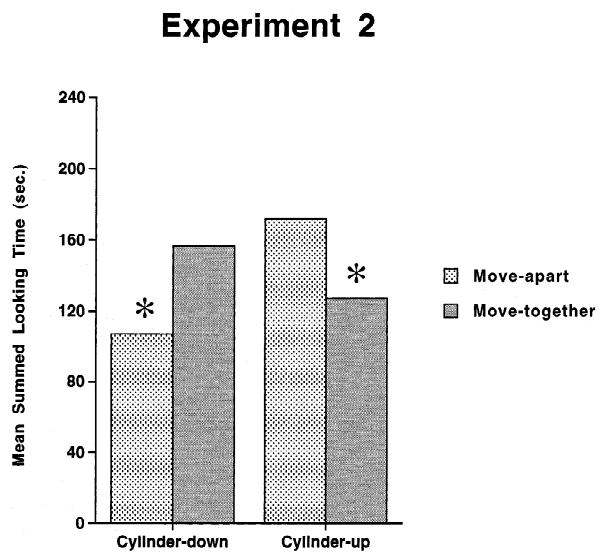

Fig. 9. Infants' mean looking times at the four test events in Experiment 2.

[4] The observers could determine whether the infants were in the cylinder-up or the cylinder-down condition by the direction of their gaze during the familiarization and test trials. The infants' gaze did not reveal, however, whether they were watching the move-apart or the move-together event during the test trials. Pilot data collected using the same procedure as in Experiment 2 revealed that, as in Experiment 1, the primary observer was unable to reliably guess which of the two test events the infants had seen.

apart) as between-subjects factors. The interaction between the cylinder position and the motion conditions was significant, $F(1, 20) = 11.24$, $p < .005$. Planned comparisons indicated that the infants in the cylinder-down condition who saw both the cylinder and box move ($M = 156.6$, $SD = 36.7$) looked reliably longer than the infants who saw only the cylinder move ($M = 107.1$, $SD = 29.9$), $F(1, 20) = 6.22$, $p < .025$, whereas the infants in the cylinder-up condition who saw only the cylinder move ($M = 171.6$, $SD = 39.6$) looked reliably longer than those who saw both the cylinder and box move ($M = 127.0$, $SD = 30.4$), $F(1, 20) = 5.05$, $p < .05$).

Although no infant in Experiment 2 looked the maximum number of seconds (60 s) allowed on all four test trials, the data of this experiment were also examined using survival analyses to provide a comparison with the results of Experiment 1 (see Experiment 1 for details). These survival analyses yielded results similar to those of the ANOVA. When the cylinder rested on the apparatus floor, the infants in the move-together condition looked reliably longer than the infants in the move-apart condition, $W(1) = 8.83$, $p < .005$. When the cylinder lay above the apparatus floor, the reverse pattern was found, $W(1) = 6.85$, $p < .01$.

9. Discussion

The infants in the cylinder-down condition looked reliably longer at the move-together than at the move-apart event, suggesting that they perceived the cylinder and box as two distinct units. In contrast, the infants in the cylinder-up condition looked reliably longer at the move-apart than at the move-together event, suggesting that they viewed the cylinder and box as a single unit.

The results of Experiment 2 confirm and extend those of Experiment 1 in three directions. First, the present results provide further evidence that, by 8 months of age, infants attend to featural information when organizing stationary adjacent displays. The results of the cylinder-down condition suggest that the infants were led by the marked featural differences between the cylinder and box to view them as distinct units. Second, the results of Experiment 2 are consistent with those of Experiment 1 in revealing that, by 8 months of age, infants bring to bear their physical knowledge when organizing displays. The results of the cylinder-up condition suggest that the infants perceived the cylinder and box as a single unit because they understood that the cylinder could not remain stable without the box's support. Finally, like the results of Experiment 1, the present results suggest that, when confronted with two conflicting interpretations of a display, one based on their configural knowledge and the other on their physical knowledge, 8-month-old infants allow the second interpretation to supersede the first. The infants in the cylinder-up condition judged the cylinder and box to form a single unit, even though they presented the same featural dissimilarities as in the cylinder-down condition, where the cylinder and box were perceived as two distinct units. We do not mean to imply that the infants in the cylinder-up condition were unaware of

the featural differences between the cylinder and box, but only that the infants disregarded these differences in segregating the display.[5]

10. Conclusion

In the Introduction, we proposed that adults bring to bear three kinds of object knowledge when segregating stationary three-dimensional displays: configural, physical, and experiential knowledge. The present research suggests that, by 8 months of age, infants use both configural and physical knowledge when organizing stationary adjacent displays. Furthermore, infants have available integration strategies that allow them to effectively combine their different expectations to resolve ambiguities or conflicts. Each of these achievements is briefly discussed below.

[5] Because we were primarily concerned with infants' responses to the displays used in Experiments 1 and 2, we did not test adults with the same displays in a controlled experimental setting. We did, however, informally solicit the judgments of a number of adults who were not informed of the goal of our research; they were simply asked to predict which portions of each display would move if one part were pulled.

In anticipating the results of these informal judgments, we were conscious that our adult subjects were likely to consider many more issues in interpreting the displays than our infant subjects did. For example, the adults might consider what materials were used to construct the displays, how they were constructed, and what uses the object(s) in the displays might have. Therefore, we felt that it would not be surprising to find similarities as well as differences in the infants' and adults' interpretations of the displays.

Of the 14 adults who saw the blade-between display, 11 (79%) reported that the octagons would move apart if one were pulled, and 3 (21%) judged that the octagons would move together. The reverse pattern of results was found for the 14 adults who saw the blade-beside display: 4 (71%) reported that the octagons would move apart if one were pulled, and 10 (29%) judged that the octagons would move together. These results suggest that, like the infants, the adults perceived the two octagons as a single unit when the blade was lowered beside them, but as separate units when the blade was lowered between them.

Of the 14 adults who saw the cylinder-up display, 13 (93%) reported that the cylinder and box would move together, and 1 (7%) claimed that the cylinder would move apart from the box. These results suggest that, like the infants, the adults used their knowledge of support to segregate the display and concluded that it must be composed of a single unit.

A more mixed result was found for the cylinder-down display. Of the 14 adults who saw the cylinder-down display, 8 (57%) responded that the cylinder would move apart from the box and 6 (43%) reported that the cylinder and box would move together. There was thus a difference between the infants' and adults' perception of the cylinder-down display: whereas the infants viewed it as comprising two separate units, the adults saw it as somewhat ambiguous. We attribute this difference to the fact that some of the adults used knowledge not available to the infants when interpreting the display. Comments from two adults provides support for this line of reasoning. One adult mentioned that she thought that the cylinder was attached to the box because the cylinder looked as though it could be used as a handle for the box. The other adult asked whether the composite object was a kind of vacuum cleaner. These comments suggest that at least some adults brought to bear experiential knowledge that led them to perceive the display as a kind of household implement. We have recently begun investigating infants' use of experiential knowledge in segregation tasks (Needham and Baillargeon, in press); some of these findings are discussed in the Conclusion section.

10.1. Configural knowledge

The infants in the blade-beside condition in Experiment 1 viewed the octagons as a single unit; in contrast, the infants in the cylinder-down condition in Experiment 2 perceived the cylinder and box as two separate units. Together, these results suggest that, by 8 months of age, infants already possess configural knowledge: they expect surfaces with similar features to belong to a single unit, and surfaces with dissimilar features to belong to distinct units.

Exactly what features of the displays did the infants in Experiments 1 and 2 consider to decide whether the displays contained one or two units? The present data are insufficient to answer this question. The displays used in Experiments 1 and 2 were purposefully selected to maximize similarities or differences between parts. Thus, the two octagons were co-planar and identical in shape, size, texture, color, and pattern; the cylinder and box, in contrast, were non-planar and different in shape, size, texture, color, and pattern. The infants may have used all or only some of the features in each display to organize it (e.g., Kellman and Shipley, 1991). Further research is necessary to specify which perceptual features contributed to the infants' interpretation of the displays.

Would infants less than 8 months of age also demonstrate configural expectations in their responses to the displays used in Experiments 1 and 2? In the Introduction, we reviewed considerable evidence that infants aged 5 months and younger lack configural knowledge and organize neither partly occluded nor adjacent displays in accordance with their featural properties. However, new findings by Needham (in press) suggest that this characterization may have been overly negative. In a series of experiments, Needham presented 7.5-, 6.5-, and 4.5-month-olds with the cylinder-down display used in Experiment 2. Only the 7.5-month-olds showed a reliable preference for the move-together over the move-apart event; the 6.5- and 4.5-month-olds tended to look equally at the two events, as though they were uncertain whether the cylinder and box formed one or two units. When presented with a *simplified* version of the display, however, both 6.5- and 4.5-month-olds were able to parse the display into two units; furthermore, the same positive result was obtained in a subsequent experiment in which a narrow screen was placed in front of the simplified cylinder-down display to create a partly occluded display.

The differences between the original and simplified versions of the cylinder-down display (Needham, in press) were rather subtle. In the original version, the ends of the cylinder curved slightly forward, its zigzag-edged shape was somewhat irregular, and the box was oriented so that a corner faced the infant. In the simplified version, the cylinder was straightened, rendering its zigzag-edged shape more regular, and the box's orientation was modified so that a side rather than a corner faced the infant. Why did these changes help the infants achieve an unambiguous interpretation of the display? In a recent chapter (Needham et al., 1997), we proposed that, in order to segregate a stationary three-dimensional display, infants must (a) *represent* the spatial and perceptual features of each surface in the display; (b) *compare* the different surfaces in the display to

determine whether their features are similar or not; and (c) *interpret* the information yielded by the first two processes in light of their configural knowledge. We further suggested that, when infants are unable to complete the first or second process adequately, the segregation of the display becomes stalled at this point – ''later'' processes do not take place, resulting in indeterminate percepts. According to this account, Needham's subjects succeeded in parsing the simplified but not the original cylinder-down display because the latter was more complex and overwhelmed their featural processing abilities. In Needham et al. (1997), we report preliminary results that further support the present account, and also reinterpret previous findings in light of the account.

The preceding discussion suggests that one important developmental difference between the 8-month-olds tested in the present research and the 6.5- and 4.5-month-olds tested by Needham (in press) has to do with the sophistication of their featural processing abilities. We do not wish to claim, however, that the only developmental change that takes place in infants' use of configural knowledge is their ability to apply this knowledge to increasingly complex displays. It seems likely that the knowledge itself becomes more elaborate over time, with infants learning to use a progressively richer set of features to organize displays. Future research is needed to specify how each developmental strand contributes to the complex pattern of positive and negative results that have been obtained in this area.

10.2. Physical knowledge

The results of Experiment 1 indicated that, in contrast to the infants in the blade-beside condition, the infants in the blade-between condition viewed the octagons as two distinct units. Similarly, the results of Experiment 2 showed that, in contrast to the infants in the cylinder-down condition, the infants in the cylinder-up condition perceived the cylinder and box as a single unit. Together, these results provide evidence that 8-month-old infants readily bring to bear their knowledge of impenetrability and support when segregating displays.

Recent findings indicate that, when learning about a new type of physical event, infants first form a preliminary, all-or-none *initial concept* that captures only the bare essence of the event; with further experience, infants slowly identify discrete and continuous *variables* that are relevant to the event (e.g., Baillargeon, 1994, Baillargeon, 1995; Baillargeon et al., 1995). This developmental model suggests that what physical knowledge infants bring to bear when organizing displays depends primarily on what initial concepts and variables infants have identified.

To illustrate, consider the development of infants' knowledge about support events. In a series of experiments, we presented infants aged 3–12.5 months with support problems involving a box and a platform (e.g., Needham and Baillargeon, in press; Baillargeon et al., 1992; see Baillargeon, 1995 for a review). We found that, by 3 months of age, infants have formed an *initial concept* centered on a contact/no-contact distinction: they expect the box to fall if it loses all contact with the platform and to remain stable otherwise. Between 3 and 12.5 months of

age, infants identify at least three variables. At about 4.5 to 5 months, infants begin to consider the *type of contact* between the box and the platform: they now expect the box to remain stable if released on the top but not against the side of the platform. At about 6.5 months, infants become aware that the *amount of contact* between the box and the platform also affects the box's stability: they now expect the box to be stable if a large but not a small portion of its bottom surface rests on the platform. Finally, at about 12.5 months of age, infants begin to attend to the *box's shape* (or weight distribution): they now expect an asymmetrical box to be stable only if the proportion of the box that lies above the platform is greater than that off the platform.

The developmental sequence just described suggests that the 8-month-old infants in Experiment 2 correctly parsed the cylinder-up display because they had already identified type of contact as a relevant variable: they understood that the cylinder could not maintain its position in space if it were merely resting against the box, and so they concluded that the two must be attached. The sequence predicts that the infants would have reached the same conclusion had they been presented with a display in which only the right edge of the cylinder lay on top of the box; the infants would have recognized that the amount of contact between the cylinder and the box was too small to ensure the box's support. Finally, the sequence predicts that the infants would have viewed the cylinder and the box as separate objects had the cylinder been twisted into an ''L'' and placed on the top of the box in such a way that half of the cylinder's horizontal segment lay on the box; at their stage of development, the infants would have judged the cylinder to be adequately supported, since half of its bottom surface rested on the box, and so they would have felt free to focus on the display's featural properties alone.

Future experiments are planned to test these and other related predictions. One advantage of such experiments, we believe, is that they make clear how tightly interwoven are infants' physical knowledge and segregation judgments, and how readily advances in one can alter the other.

10.3. Experiential knowledge

Although the present experiments did not address infants' use of experiential knowledge, we have recently completed a series of experiments on this issue (Needham and Baillargeon, in press) whose results have implications for the present research. In these experiments, we presented 4.5-month-old infants with the cylinder-down display used in Experiment 2. We followed the same procedure as Needham (in press), with one exception: the infants were shown the box alone for 5 s prior to seeing the whole display. The results indicated that this brief exposure to the box was sufficient to help the infants segregate the display into two distinct units. Positive results were also obtained when the exposure to the box took place in the infants' homes 24 h before they were tested with the cylinder-down display. A prior experience with the box – even when brief or removed in time and context – thus made it possible for the infants to organize the display: they could not do so based on a featural analysis of the display (Needham, in

press), but they did succeed when they were able to recognize the box and segregate it from the adjacent cylinder.

The findings just described suggest interesting directions for future research. Consider the infants in the cylinder-down condition in Experiment 2 who watched the move-together event. These infants saw an event inconsistent with the interpretation suggested by the featural properties of the display (two units). What if the infants were brought back to the lab the next day or the next week, and shown the same display again? Would the infants allow their experiential knowledge (one unit) to override the interpretation suggested by their configural knowledge (two units)? Furthermore, how would infants respond if presented, on their return to the lab, with a similar but not identical version of the display (e.g., one that involved a box of a different color and pattern)? Evidence that the infants readily generalized what they had learned about the first display to the second (one unit) would suggest that infants, like adults, can use knowledge about single objects as well as object categories to parse displays (recall the ''household implement'' shown in Fig. 3).

10.4. Integration strategies

In Experiment 1, the infants perceived the two octagons as a single unit when the blade was placed next to them, and as two units when the blade was inserted between them. In Experiment 2, the infants perceived the cylinder and the box as two units when both rested on the apparatus floor, and as a single unit when the cylinder rested above the apparatus floor. The infants thus seemed to employ a strategy for combining the featural and physical information in each display that allowed the physical interpretation to supersede the featural one.

How might infants develop such an integration strategy? One possibility is that it is simply the result of experience: infants might learn across situations that when a display has conflicting configural and physical interpretations, it is usually better (e.g., in terms of predicting object displacements) to adopt the latter rather than the former.

Another, intriguing possibility is that infants' integration strategy reflects an important difference in their representations of physical and configural rules. Specifically, infants might represent physical rules as more certain, and configural rules as more probabilistic. The data (i.e., observations and manipulations) infants collect about physical rules are generally consistent or homogeneous. Objects that are released in mid-air – as when parents drop clothes in baskets, peas in pots, or ice cubes in glasses – typically fall; balloons are one of the few exceptions to this rule. The data infants gather about configural rules, on the other hand, must be less consistent. In their daily worlds, infants must see quite a few objects – toys, pacifiers, kitchen utensils – that are composed of perceptually distinct parts and yet move as single objects. Thus, it might be that physical and configural rules have associated with them a ''strength'' value that corresponds to the consistency of the data on which they are based. Integrating conflicting interpretations of a

display, on this view, would involve comparing the relative strengths of the relevant rules and selecting the interpretation associated with the higher value.

10.5. Final remarks

The results of the present experiments suggest that 8-month-old infants' ability to segregate unfamiliar three-dimensional displays is far more sophisticated than was previously known. Infants this age make use of both configural and physical knowledge to organize stationary adjacent displays. Furthermore, infants respond in remarkably adult-like ways when faced with conflicting featural and physical interpretations, selecting the latter over the former. The present research is significant in that it not only contributes to our understanding of infants' object segregation, but also helps shed light on the complex and fascinating interplay between perceptual and cognitive development in infancy.

Acknowledgments

This research was supported by grants from the National Institute of Child Health and Human Development to the first (FIRST grant HD-32129) and the second (grants HD-28686 and HD-21104) author. We wish to thank Cindy Fisher and Lisa Kaufman, for helpful comments and suggestions; Stanley Wasserman and Kevin Miller, for their patient and gracious statistical advice on the survival analyses; James Hershey, for carrying out these analyses; and Elizabeth Cullum, for conducting the other data analyses. We also thank Susan Garland-Bengur, Jason Botwick, Lincoln Craton, Julie DeVos, Myra Gillespie, Valerie Kolstad, Laura Kotovsky, and the undergraduate students working in the Infant Perception Laboratory at Duke University and in the Infant Cognition Laboratory at the University of Illinois, for their help with the data collection. Finally, we thank the parents who kindly agreed to have their infants participate in the experiments.

References

Atkinson, J., & Braddick, O. (1992). Visual segmentation of oriented textures by infants. *Behavioural Brain Research*, *49*, 123–131.

Baillargeon, R. (1987). Object permanence in 3.5- and 4.5-month-old infants. *Developmental Psychology*, *23*, 655–664.

Baillargeon, R. (1991). Reasoning about the height and location of a hidden object in 4.5- and 6.5-month-old infants. *Cognition*, *38*, 13–42.

Baillargeon, R. (1994). How do infants learn about the physical world? *Current Directions in Psychological Science*, *3*, 133–140.

Baillargeon, R. (1995). A model of physical reasoning in infancy. In C. Rovee-Collier & L. Lipsitt (Eds.), *Advances in infancy research* (Vol. 9). Norwood, NJ: Ablex.

Baillargeon, R., & DeVos, J. (1991). Object permanence in young infants: Further evidence. *Child Development*, *62*, 1227–1246.

Baillargeon, R., Kotovsky, L., & Needham, A. (1995). The acquisition of physical knowledge in infancy. In D. Sperber, D. Premack, & A.J. Premack (Eds.), *Causal cognition: A multidisciplinary debate*. Oxford: Clarendon Press.

Baillargeon, R., Needham, A., & DeVos, J. (1992). The development of young infants' intuitions about support. *Early Development and Parenting*, *1*, 69–78.

Baillargeon, R., Raschke, H., & Needham, A. (1996). Should objects fall when placed on or against other objects? The development of young infants' reasoning about support. Manuscript in preparation.

Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, *94*, 115–147.

Biederman, I., Mezzanotte, R., & Rabinowitz, J. (1982). Scene perception: Detecting and judging objects undergoing relational violations. *Cognitive Psychology*, *14*, 143–177.

Bornstein, M.H. (1985). Infant into adult: Unity to diversity in the development of visual categorization. In J. Mehler & R. Fox (Eds.), *Neonate cognition: Beyond the blooming buzzing confusion*. Hillsdale, NJ: Erlbaum.

Bornstein, M., & Krinsky, S. (1985). Perception of symmetry in infancy: The salience of vertical symmetry and the perception of pattern wholes. *Journal of Experimental Child Psychology*, *39*, 1–19.

Colombo, J., Laurie, C., Martelli, T., & Hartig, B. (1984). Stimulus context and infant orientation discrimination. *Journal of Experimental Child Psychology*, *37*, 576–586.

Craton, L.G. (1993, March). *Infants' perception of the unity and appearance of stationary, partially occluded objects*. Paper presented at the meeting of the Society for Research in Child Development, New Orleans, LA.

Craton, L.G. (1996). The development of perceptual completion abilities: Infants' perception of stationary, partially occluded objects. *Child Development*, *67*, 890–904.

Dixon, W.J. (Ed.) (1992). *BMDP statistical software manual*. Berkeley: University of California Press.

Fodor, J. (1983). *The modularity of mind*. Cambridge, MA: MIT Press.

Fodor, J., & Pylyshyn, Z. (1981). How direct is visual perception? Some reflections on Gibson's ''Ecological Approach.'' *Cognition*, *9*, 139–196.

Ghim, H. (1990). Evidence for perceptual organization in infants: Perception of subjective contours by young infants. *Infant Behavior and Development*, *13*, 221–248.

Ghim, H., & Eimas, P. (1988). Global and local processing by 3- and 4-month-old infants. *Perception and Psychophysics*, *43*, 165–171.

Gibson, J.J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Giffen, K.V., & Haith, M.M. (1984). Infant visual response to gestalt geometric forms. *Infant Behavior and Development*, *7*, 335–346.

Granrud, C., Haake, R., & Yonas, A. (1985). Infants' sensitivity to familiar size: The effect of memory on spatial perception. *Perception and Psychophysics*, *37*, 459–466.

Hofsten, C. von, & Spelke, E.S. (1985). Object perception and object-directed reaching in infancy. *Journal of Experimental Psychology: General*, *114*, 198–212.

Hummel, J., & Biederman, I. (1992). Dynamic binding in a neural network for shape recognition. *Psychological Review*, *99*, 480–517.

Kanizsa, G. (1979). *Organization in vision*. New York: Praeger.

Kellman, P.J., Gleitman, H., & Spelke, E. (1987). Object and observer motion in the perception of objects by infants. *Journal of Experimental Psychology: Human Perception and Performance*, *13*, 586–593.

Kellman, P.J., & Shipley, T. (1991). A theory of visual interpolation in object perception. *Cognitive Psychology*, *23*, 141–221.

Kellman, P.J., & Spelke, E.S. (1983). Perception of partly occluded objects in infancy. *Cognitive Psychology*, *15*, 483–524.

Kellman, P.J., Spelke, E.S., & Short, K.R. (1986). Infant perception of object unity from translatory motion in depth and vertical translation. *Child Development*, *57*, 72–76.

Kestenbaum, R., Termine, N., & Spelke, E.S. (1987). Perception of objects and object boundaries by three-month-old infants. *British Journal of Developmental Psychology*, *5*, 367–383.

Lee, E.T. (1992). *Statistical methods for survival data analysis* (2nd ed.). Wiley: New York.

Marr, D. (1982). *Vision*. San Francisco: Freeman.
Michaels, C., & Carello, C. (1981). *Direct perception*. New York: Prentice Hall.
Michotte, A., Thines, G., & Crabbe, G. (1964). *Les complements amodaux des structures perceptives. Studia Psychologica*. Louvain: Publications Universitaires de Louvain.
Milewski, A.E. (1979). Visual discrimination and detection of configurational invariance in 3-month-old infants. *Developmental Psychology, 15*, 357–363.
Needham, A. (in press). Infants' use of featural information to segregate stationary objects. *Infant Behaviour and Development*.
Needham, A., & Baillargeon, R. (1993). Intuitions about support in 4.5-month-old infants. *Cognition, 47*, 121–148.
Needham, A., & Baillargeon, R. (in press). Effects of prior experience on 4.5-month-old infants' object segregation. *Infant Behavior and Development.*
Needham, A., Baillargeon, R., & Kaufman, L. (1997). Object segregation in infancy. In L. Lipsitt & C. Rovee-Collier (Eds.), *Advances in Infancy Research, 11.*
Palmer, S. (1975). The effects of contextual scenes on the identification of objects. *Memory and Cognition, 3*, 519–526.
Piaget, J. (1954). *The construction of reality in the child*. New York: Basic Books.
Rock, I. (1975). *An introduction to perception*. New York: Macmillan.
Rock, I. (1983). *The logic of perception*. Cambridge, MA: MIT Press.
Salapatek, P. (1975). Pattern perception in early infancy. In L.B. Cohen & P. Salapatek (Eds.), *Infant perception: From sensation to cognition. Basic visual processes* (Vol. 1). New York: Academic Press.
Schmidt, H., & Spelke, E.S. (1984, April). *Gestalt relations and object perception in infancy*. Paper presented at the International Conference on Infant Studies, New York.
Schmidt, H., Spelke, E., & LaMorte, V. (1986, April). *The development of Gestalt perception in infancy*. Paper presented at the International Conference on Infant Studies, Los Angeles.
Shepard, R. (1983). Ecological constraints on internal representation: Resonant kinematics of perceiving, imagining, thinking, and dreaming. *Psychological Review, 91*, 417–447.
Slater, A., Morison, V., Somers, M., Mattock, A., Brown, A., & Taylor, D. (1990). Newborn and older infants' perception of partly occluded objects. *Infant Behavior and Development, 13*, 33–49.
Spelke, E.S. (1985). Preferential looking methods as tools for the study of cognition in infancy. In G. Gotlieb & N. Krasnegor (Eds.), *Measurement of audition and vision in the first year of postnatal life*. Norwood, NJ: Ablex.
Spelke, E.S. (1988). Where perceiving ends and thinking begins: The apprehension of objects in infancy. In A. Yonas (Ed.) *Perceptual development in infancy*. Minnesota Symposium on Child Psychology, Vol. 20. Hillsdale, NJ: Erlbaum.
Spelke, E.S. (1990). Principles of object perception. *Cognitive Science, 14*, 29–56.
Spelke, E.S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review, 4*, 605–632.
Spelke, E.S., Breinlinger, K., Jacobson, K., & Phillips, A. (1993). Gestalt relations and object perception: A developmental study. *Perception, 22*, 1483–1501.
Spelke, E.S., Hofsten, C. von, & Kestenbaum, R. (1989). Object perception and object-directed reaching in infancy: Interaction of spatial and kinetic information for object boundaries. *Developmental Psychology, 25*, 185–196.
Spelke, E.S., & Van de Walle, G. (1993). Perceiving and reasoning about objects: Insights from infants. In N. Eilan, W. Brewer, & R. McCarthy (Eds.), *Spatial representation*. Oxford: Basil Blackwell.
Termine, N., Hrynick, R., Kestenbaum, R., Gleitman, H., & Spelke, E.S. (1987). Perceptual completion of surfaces in infancy. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 524–532.
Treiber, F., & Wilcox, S. (1980). Perception of a ''subjective'' contour by infants. *Child Development, 51*, 915–917.
Turvey, M., Shaw, R., Reed, E., & Mace, W. (1981). Ecological laws of perceiving and acting: In reply to Fodor and Pylyshyn (1981). *Cognition, 9*, 237–304.
Ullman, S. (1980). Against direct perception. *Behavioral and Brain Sciences, 3*, 373–415.
Ullman, S. (1986). Visual routines: Where bottom-up and top-down processing meet. In *Pattern recognition by humans and machines* (Vol. 2). New York: Academic Press.