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ADVANCES IN INFANCY RESEARCH

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criteria were that probes elicit a nonzero blink response on at least two trials in each dull condition and on at least one trial in each interesting condition.
5. Observers were technicians unaware of the hypothesis being tested, the interest value of the visual foregrounds, and, at the time of ratings, the modality of the probe to be delivered. Fixation was rated as off the slide, on the slide but off center, or on slide center.
6. A pilot study of four infant-mother pairs showed that any maternal response to probes has negligible effects on infant blinking. Under conditions similar to those of the main experiment, only the mother received blink-eliciting acoustic probes while the infant observed interesting slides. Three infant blinks, averaging three digitized units, were recorded on the 40 trials of 43 that elicited measurable maternal response averaging 950 units.
7. L. D. Silverstein and F. K. Graham, *Psychophysiology 15,* 377 (1978).
8. F. K. Graham, in *The Orienting Reflex in Human,* H. D. Kimmel, E. H. van Olst, J. F. Orlebeke, Eds. (Erlbaum, Hillsdale, N.J., 1979), p. 137; F. K. Graham and R. K. Clifton, *Psychol. Bull. 65,* 305 (1966); J. I. Lacey and B. C. Lacey, in *Physiological Correlates of Emotion,* P. Black, Ed. (Academic Press, New York, 1970), p. 295; A. Schell and J. Catania, *Psychophysiology 12,* 147 (1975).
9. The scoring program discarded trials if EMG activity was present at the time of probe onset (indicating a blink in progress) or if peak latency exceeded 450 msec. Onset and peak latency windows were increased beyond previously described values [F. K. Graham, B. D. Strock, B. L. Zeigler, in *Aspects of the Development of Competence,* W. A. Collins, Ed. (Erlbaum, Hillsdale, N.J., 1981), vol. 14, p. 1] to accommodate the longer latency of the visual blink reflex (mean onset latencies; acounstic, 60 msec; visual, 180 msec). For details of scoring program, see F. K. Graham, L. E. Putnam, and L. A. Leavitt [*J. Exp. Psychol: Human Percept. Perform. 1,* 161 (1975)] or B. D. Strock [thesis, University of Wisconsin (1981)].
10. B. J. Athony and F. K. Graham, unpublished data.
11. S. A. Hackley, M. A. thesis, University of Wisconsin (1981)
12. J. A. Deutsch and D. Deutsch, *Psychol. Rev. 70,* 80 (1963); D. A. Norman, *ibid. 75,* 522 (1968); R. M. Shiffrin and W. Schneider, *ibid. 84,* 127 (1977); M. I. Posner and D. R. Snyder, in *Information Processing and Cognition,* R. L. Solso, Ed. (Erlbaum, Hillsdale, N.J., 1975), p. 55.
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OBJECT SEGREGATION IN INFANCY*

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I. INTRODUCTION

Recent research suggests that young infants are surprisingly adept at recognizing (e.g., Bahrick & Pickens, in press; Fagan, 1973; Rovee-Collier & Hayne, 1987), categorizing (e.g., Eimas, 1994; Greco, Hayne, & Rovee-Collier, 1990; Quinn & Eimas, in press), and enumerating objects (e.g., Canfield & Smith, in press; Simon, Hespos, & Rochat, 1995; Wynn, 1992), as well as at reasoning about objects' displacements and interactions with other objects (e.g., Baillargeon, Kotovsky, & Needham, 1995; Needham & Baillargeon, 1993; Spelke, Breinlinger, Macomber, & Jacobson, 1992). All of these remarkable achievements are predicated on infants' being able to *segregate* objects—to determine what surfaces in a visual scene belong together as objects and what surfaces do not.

There is evidence that, from a very early age, infants use spatial information to organize displays, and view spatially continuous surfaces as belonging to the same object and spatially discontinuous surfaces as belonging to distinct objects (e.g., Slater et al., 1990; Slater, Johnson, Kellman, & Spelke, 1994; Spelke & Born, 1984). Use of spatial information would lead infants to group the horizontal and vertical surfaces of the box in Figure 1A correctly into a single object. Reliance on spatial information would also lead infants to perceive the box and ball in Figure 1B correctly as separate objects. However, exclusive use of spatial information would lead infants to misinterpret the adjacent and partly occluded displays in Figures 1C and 1D. To achieve a veridical perception of Figure 1C, infants must parse the spatially continuous arrangement of the box and ball into two distinct objects. Conversely, to arrive at a correct interpretation of Figure 1D, infants must group spatially discontinuous surfaces—the portions of the box visible to the left and right of the ball—into a single object.

How successful are young infants at segregating stationary adjacent and partly occluded displays such as those in Figures 1C and 1D? How do infants' segregation abilities develop with age? This chapter addresses these questions.

II. THREE TYPES OF OBJECT KNOWLEDGE

Researchers have long been interested in identifying the various factors that affect adults' organization of displays. One such factor, adults' knowledge about objects, was discussed long ago by James (1890). Many investigators have since incorporated this factor into their accounts of how adults (and, in some cases, machines) interpret visual stimuli (e.g., Biederman, 1987; Gregory, 1980; Hummel & Biederman, 1992; Humphreys & Bruce, 1989; Kellman & Spelke, 1983; Marr, 1982; Minsky, 1975; Shepard, 1983; Spelke, 1982, 1985a, 1988, 1991). Following these investigators' lead, we distinguish between three types of object knowledge that adults draw on when segregating displays: configural, physical, and experiential knowledge.

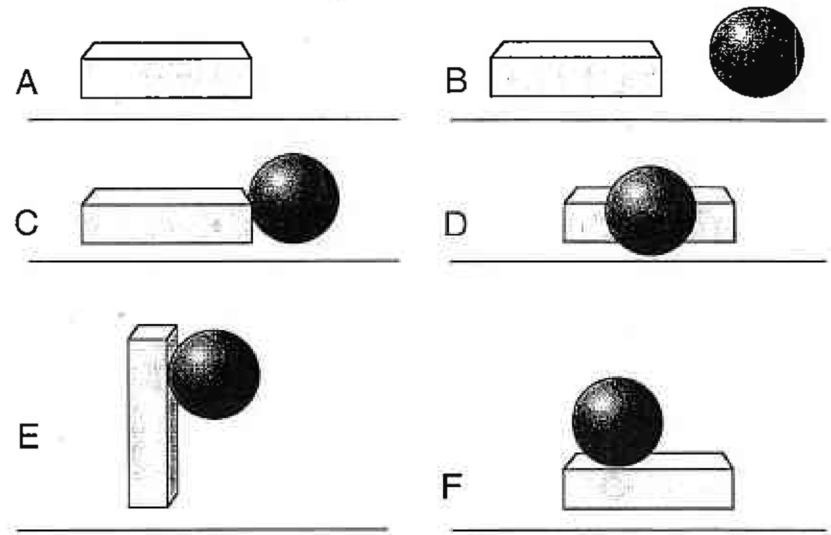

Fig. 1. A-F. See text for description.

Configural knowledge refers to adults' expectations about how objects typically appear: Adults recognize that objects are generally regular in shape, pattern, color, and texture. As a result, adults tend to group surfaces that present the same featural properties into the same units, and surfaces that present different featural properties into separate units. Thus, using configural knowledge to analyze the adjacent display in Figure 1C would enable us to see the box and ball as distinct objects, because of the marked differences in their features. The same knowledge applied to the partly occluded display in Figure 1D would lead us to group the portions of the box visible to the left and right of the ball into a single object, because of the marked similarities in their featural properties.

Physical knowledge refers to adults' beliefs about the lawful ways in which objects can move and interact, such as the beliefs that objects cannot remain stable without support and cannot move through space occupied by other objects. Use of our physical knowledge would lead us to see the box and ball in Figure 1E as a single unit, because we would realize that the ball could not retain its position without being attached to the box.

Experiential knowledge corresponds to adults' knowledge of what specific objects, or types of objects, exist in the world. This knowledge involves representations of particular objects as well as more abstract representations of object categories. Once we had encountered the display in Figure 1E, our experiential knowledge might lead us to view Figure 1F as a single unit, namely, the same box-and-ball display as in Figure 1E, now shown in a different orientation.

The segregation process thus requires the integration of several types of object knowledge, each of which can potentially suggest a different interpretation of a display. Indeed, conflicting interpretations can arise not only between but also within each type of object knowledge. For example, infants might be faced with a display in which different features (e.g., shape and pattern) yielded inconsistent interpretations of the display's composition. The development of infants' segregation process must thus involve at least two main tasks: first, the acquisition of different types of object knowledge, and second, the development of strategies for integrating conflicting information so as to maximize the likelihood of veridical perceptions.

In the following sections, we review research conducted in our laboratories and elsewhere on young infants' use of configural, experiential, and physical knowledge in organizing partly occluded and adjacent displays. To anticipate, this review suggests that young infants, like adults, use all three types of object knowledge when segregating displays. In the final section, we briefly consider the implications of these findings for characterizations of perceptual development in infancy.

III. INFANTS' USE OF CONFIGURAL KNOWLEDGE

A. Prior Findings

Until recently, most of the research on the organization of stationary three-dimensional displays in infancy focused on young infants' use of configural knowledge (see Kellman & Shipley, 1991; Spelke, 1991; and Spelke & Van de Walle, 1993, for recent reviews). Investigators typically concluded 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.

Some of the evidence for this conclusion came from experiments (see Figure 2) on young infants' perception of partly occluded displays (e.g., Bower, 1967; Craton, 1993, 1996; Kellman & Spelke, 1983; Schmidt & Spelke, 1984; Termine, Hrynick, Kestenbaum, Gleitman, & Spelke, 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. Next, 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 that were visible above and below the block in the habituation display. The infants looked about equally at the two displays, suggesting that they were uncertain whether the rod segments visible in the habituation display belonged to a single object that extended behind the block. The same ambiguous percept was observed in subsequent experiments in which the rod was replaced with a triangular rod figure (Kellman & Spelke, 1983), a two-dimen-

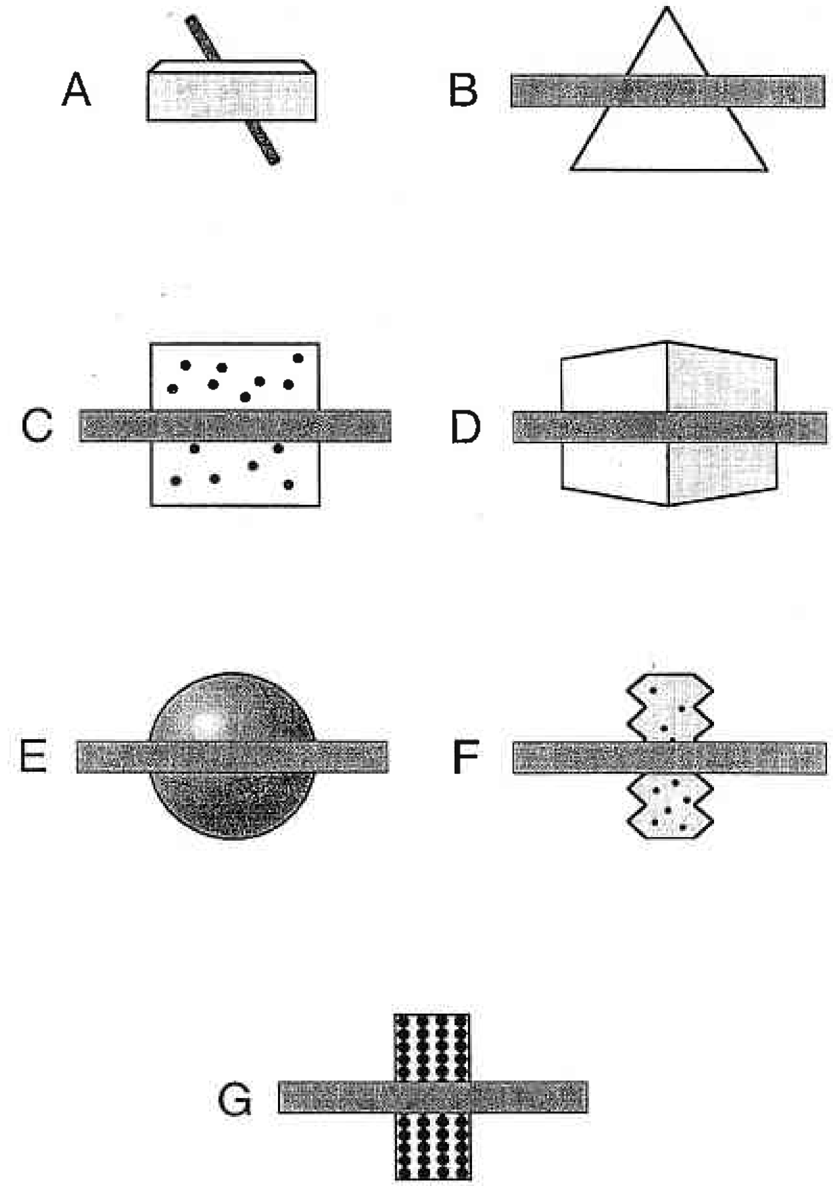

Fig. 2. Schematic drawing of the similar displays used in (A) and (B) Kellman and Spelke (1983); (C) Termine et al. (1987); (D) and (E) Schmidt and Spelke (1984); (F) Craton (1993); and (G) Crato(1996).

sional surface (Termine et al., 1987) a cube or sphere (e.g., Schmidt & Spelke, 1984), or, in experiments conducted with 5-month-old infants, a rectangular box with jagged edges (Craton, 1993), or a surface with a salient dot pattern (Craton, 1996). These results were taken to suggest that infants aged 4 to 5 months do not attend to featural information when organizing partly occluded displays.

Investigations of infants' perception of adjacent displays led to a similar conclusion (e.g., Piaget, 1954; Spelke, Breinlinger, Jacobson, & Phillips, 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 (see Figure 3A). 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 thus appeared consistent in suggesting that 4- to 5-month-old infants do not segregate displays in accordance with their featural properties. One concern in accepting this conclusion, however, was that most of the evidence supporting it was derived from experiments that made use of *similar* displays—displays that required infants to group together surfaces that were similar in shape, pattern, color, and texture. Before accepting the conclusion that young infants do not attend to featural information, it seemed important to investigate their response to *dissimilar* displays. Evidence that infants had an ambiguous perception of dissimilar as well as similar displays would strengthen the conclusion that young infants lack configural expectations. On the other hand, evidence that young infants formed clear, unambiguous interpretations of dissimilar displays as composed of distinct objects would suggest that young infants (a) possess at least some configural knowledge and (b) are better at organizing dissimilar displays than at organizing similar displays.

One finding reported by Spelke et al. (1993) provided an intriguing hint that young infants might respond differently to similar and dissimilar displays (different findings by Schmidt, Spelke, & LaMorte, 1986, are discussed in Section IIIC below). In addition to the bell-shaped display described above, Spelke et al. also showed 5-month-old infants a dissimilar adjacent display (see Figure 3B) composed of two parts that differed in shape and color (to create this display, the lower half of the bell-shaped display was placed on its top half, and the two halves were painted different colors). Following habituation to the display, the infants saw move-together and move-apart test events, as before. The results suggested that the infants preferred the move-together over the move-apart event, as though they perceived the display as composed of two units and hence were surprised to see it move as one. Because the difference between the responses of the infants who

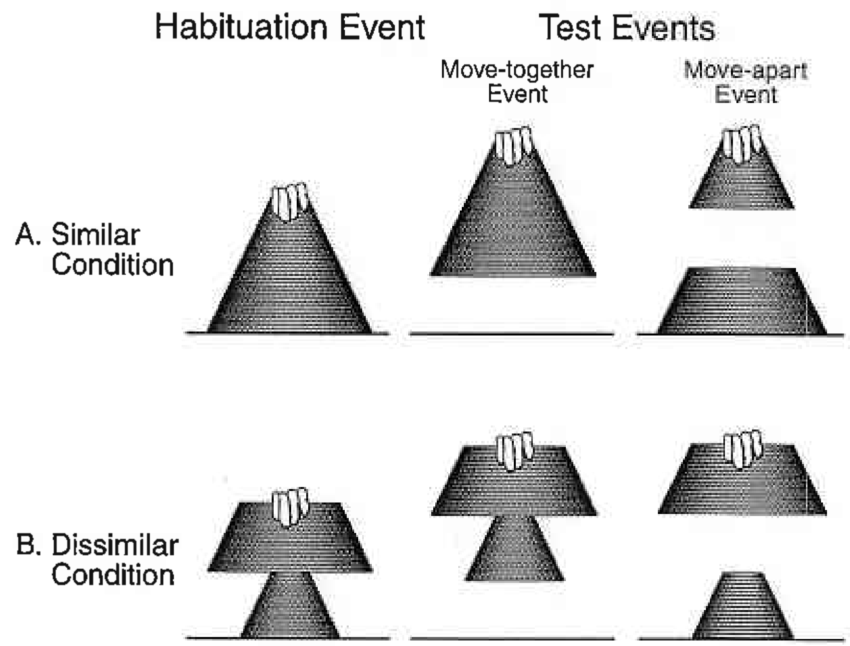

Fig. 3. Schematic drawing of the events shown to the infants in the similar (3A) and the dissimilar (3B) condition in Spelke et al. (1993).

were shown the similar and the dissimilar adjacent displays was only marginally significant, further experiments were needed before any firm conclusion could be reached. In the following sections, we report experiments conducted in our laboratories that examined young infants' responses to similar and dissimilar partly occluded and adjacent displays. Before describing these experiments, we first say a few words about our experimental procedure.

B. General Method

The method used in our experiments was adapted from that devised by Spelke et al. (1993). The infants participated in a two-phase procedure that consisted of a familiarization phase and a test phase. During the *familiarization* phase, the infants were given the opportunity to observe a stationary display and form an interpretation of its composition. Some displays were partly occluded displays and others adjacent displays; some displays were composed of two similar parts and others of two dissimilar parts. During the *test* phase, the infants saw test events in which a gloved hand took hold of one part of the display and moved it a short distance. For half of the infants, the other part in the display remained stationary (move-apart condition); for the other infants, the two parts moved as a whole (move-together condition). The rationale was that if the infants perceived the stationary display as a single unit, they would expect it to move as a whole and be surprised when it did not. Conversely, if the infants viewed the stationary display as composed of more than one unit, they would expect the units to move independently and be surprised when they did not. Because infants' surprise at an event typically manifests itself by prolonged attention to the event (e.g., Bornstein, 1985; Spelke, 1985b), the infants were expected to look reliably longer at whichever test event depicted the motion inconsistent with their interpretation of the stationary display.

In each experiment, the infant sat on a parent's lap in front of an apparatus consisting of a large display box. The parent was asked to remain calm and neutral, and to close his or her eyes during the test trials.

The infant's looking behavior was monitored by two observers who watched the infant through peepholes in large cloth-covered frames on either side of the apparatus. The observers could not see the familiarization and test events from their viewpoints, and they were not told which condition and/or experiment was being conducted. Each observer held a button box linked to a computer and depressed the button when the infant attended to the events. Each trial was divided in 100-ms intervals, and the computer determined in each interval whether the two observers agreed on the direction of the infant's gaze. Interobserver 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. Mean agreement per trial per infant averaged 92% or higher across experiments. The computer used the primary observer's looking times to determine the end of the trials (see below).

At the back of the apparatus was an experimenter who produced the familiarization and test events. The actions of the experimenter followed precise, second-by-second scripts that were practiced until they were performed smoothly and accurately. A metronome helped the experimenter adhere to the scripts.

The infants received one to three familiarization trials at the start of the experiment. A familiarization trial typically ended when the infant either (a) looked away from the display for 2 consecutive seconds or (b) looked at the display for a maximum of 30 cumulative seconds. Following the familiarization trial(s), the infants received two to six test trials (experiments with older subjects typically had two to four trials, and experiments with younger subjects three to six trials). In each test trial, the event (move-together or move-apart event) was repeated continuously until the computer signaled the end of the trial. A test trial typically ended when the infant either (a) looked away from the event for 2 consecutive seconds or (b) looked at the event for a maximum of 60 cumulative seconds. When a trial ended, an experimenter lowered a curtain in front of the apparatus. During the intertrial interval, the test objects were quickly returned to their starting positions, and the curtain was then again lifted to begin a new trial.

All of the experiments we report in the chapter made use of a between-subjects design: The infants saw either the move-together or the move-apart event across test trials. We opted for this design rather than for the within-subjects design adopted by Spelke et al. (1993) and others (e.g., Kellman & Spelke, 1983; Termine et al., 1987) because we were concerned about contamination effects with repeated alternating trials. Consider, for example, an infant who is presented with a similar adjacent display and perceives it as a single unit. Let us assume that on the first test trial, the infant sees the move-apart event and on the second test trial the move-together event. The infant should show surprise at the move-apart event because it violates her interpretation of the display; the infant might also show surprise at the move-together event, however, because it leads to an interpretation (one unit) inconsistent with that suggested by the move-apart event (two units) presented on the first trial. Because such contamination effects would tend to mask differences in infants' responses to the move-together and move-apart events, subjects were shown the same event across trials.

Finally, the number of infants tested in each condition ranged from 6 to 18 across experiments. The infants' looking times at the move-apart and move-together test events were typically compared by means of analyses of variance and planned comparisons. Results are reported as statistically reliable if the p values associated with them were equal to or smaller than .05.

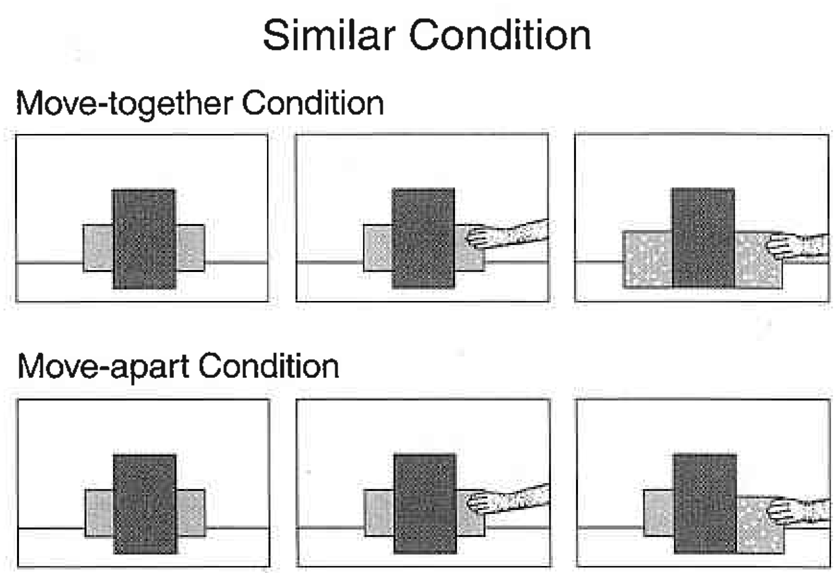

Fig. 4. Schematic drawing of the events shown to the infants in the similar condition in Needham et al. (1997).

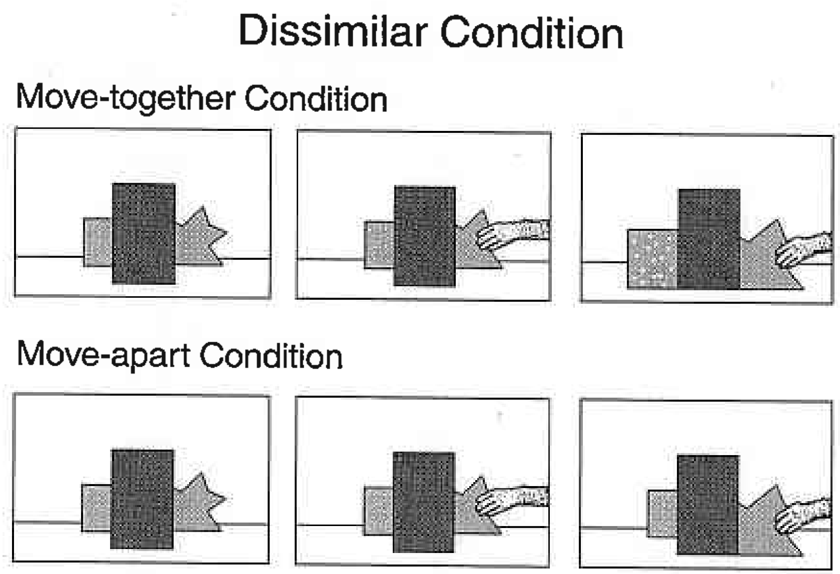

Fig. 5. Schematic drawing of the events shown to the infants in the dissimilar condition in Needham et al. (1997).

C. Experiments With Partly Occluded Displays

Our research on young infants' configural knowledge began with an investigation of 3.5- to 4.5-month-old infants' responses to partly occluded displays (Needham, Kaufman, & Baillargeon, 1997). The infants were randomly assigned to either the similar (see Figure 4) or the dissimilar condition (see Figure 5). The infants in the similar condition first received three familiarization trials during which they saw a stationary partly occluded display consisting of two rectangular boxes standing behind the left and right edges of a tall blue screen; the boxes were made of red cardboard and were decorated with small white dots. The infants in the dissimilar condition saw the same red box behind the left edge of the screen and an irregularly shaped box covered with light green fabric behind the right edge of the screen. After the familiarization trials, the infants saw a test event in which a gloved hand took hold of the right box and pulled it a short distance toward the screen. For half of the infants in each condition, the box to the left of the screen moved with the right box (move-together condition); for the other infants, the left box remained stationary throughout the event (move-apart condition). The featural similarity (similar versus dissimilar) and motion (move-together versus move-apart) factors were thus completely crossed to form four different experimental groups.

Our reasoning was as follows: If young infants were completely insensitive to the featural properties of displays, as prior results with similar partly occluded displays suggested (e.g., Craton, 1993, 1995; Kellman & Spelke, 1983; Schmidt & Spelke, 1984; Termine et al., 1987), there should be no difference between the responses of the infants in the similar and the dissimilar conditions. The infants in both conditions should look equally at the move-together and the move-apart events.

However, if young infants possessed some limited ability to group surfaces on the basis of their featural properties, as suggested by the results of Spelke et al. (1993), then different patterns of looking might be obtained in the similar and the dissimilar conditions. For example, the infants in the similar condition might look equally at the move-apart and the move-together events, suggesting an ambiguous perception of the similar display; in contrast, the infants in the dissimilar condition might look reliably longer at the move-together than at the move-apart event, revealing an unambiguous perception of the dissimilar display as composed of separate units.

To our surprise, we found that reliably different looking patterns were produced by the younger (3 months, 16 days to 4 months, 7 days) and the older (4 months, 8 days to 4 months, 14 days) infants in the experiment. Let us first consider the results obtained with the younger, 4-month-old infants. The infants in the similar condition tended to look equally at the move-apart and move-together events, suggesting that they (a) were uncertain whether the two red boxes belonged to the same or to different units and hence (b) could not predict whether the boxes should move together or apart. This finding was of course consistent with prior findings concerning 4-month-old infants' responses to similar partly occluded displays (e.g., Kellman & Spelke, 1983; Schmidt & Spelke, 1984; Termine et al., 1987). Interestingly, the looking pattern observed in the dissimilar condition was reliably different from that obtained in the similar condition. The infants looked reliably longer at the move-together than at the move-apart event, suggesting that they (a) perceived the red and green boxes as separate units and thus (b) expected the red box to remain stationary when the green box was moved and were surprised in the move-together event when this expectation was violated.

Let us now turn to the results obtained with the older, 4.5-month-old infants. The infants in the dissimilar condition performed in the same manner as the 4-month-old infants. They looked reliably longer at the move-together than at the move-apart event, suggesting that they had an unambiguous perception of the dissimilar display as involving two distinct units. Unlike the younger infants, however, the older infants in the similar condition showed a reliable preference for the move-apart over the move-together event, suggesting that they (a) viewed the similar display as composed of a single red box that extended behind the screen and therefore (b) expected this box to move as a whole and were surprised when it did not.

Because the results obtained with the 4.5-month-old infants in the similar condition were unexpected, two additional groups of 4.5-month-olds were tested. One group again saw two rectangular red boxes with white dots, and the other group saw two rectangular light green boxes with white dots. Both groups of infants looked reliably longer at the move-apart than at the move-together event, suggesting that they perceived the two red or the two green boxes as forming a single unit that extended behind the screen.

Together, the results presented in this section suggest that, contrary to earlier claims, young infants attend to featural information when organizing partly occluded displays. Both the 4- and the 4.5-month-olds in the dissimilar condition were led by the featural differences between the rectangular red box and the irregularly shaped green box to view them as distinct objects. Furthermore, the 4.5-month-old infants in the similar condition and its replication perceived the identical boxes on either side of the screen as belonging to the same object. These findings provide evidence that, by 4 months of age, infants possess configural knowledge and organize at least some displays in accordance with their featural properties.

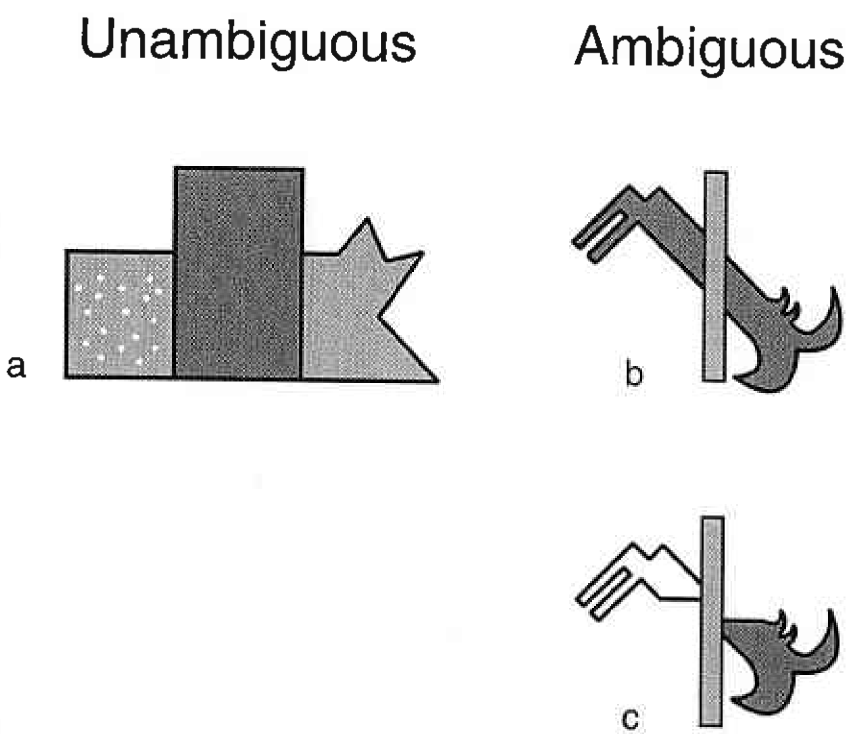

Fig. 6. Schematic drawing of the dissimilar displays used in (A) Needham et al. (1997); and (B) and (C) Schmidt et al. (1986).

The present results also raise a number of questions about apparent inconsistencies in young infants' responses to displays. Three such inconsistencies will be noted here. First, consider the results obtained in the dissimilar condition. These data are at odds with findings (see Figure 6) reported by Schmidt et al. (1986). In this experiment, 5-month-old infants were habituated to one of two dissimilar partly occluded displays involving nonsense forms visible on either side of a narrow screen. In one display, the forms were different in shape but uniform in color. In the other display, the forms differed in both shape and color and were also nonplanar and misaligned. Following habituation, the screen was removed, and the infants saw complete and incomplete versions of the habituation displays. The infants in both conditions tended to look equally at the test displays they were shown, suggesting that their perceptions of the habituation displays were indeterminate.

How can one reconcile these ambiguous responses with the positive results obtained in the present research with the dissimilar display? Could this discrepancy reflect differences in the configural knowledge needed to correctly interpret the various displays? A more likely explanation, we believe, is that the discrepancy stems from differences in earlier steps in the segregation process. In order to bring their configural knowledge to bear on a display, infants must engage in at least three processes. They must (a) encode or represent the featural properties of each surface in the display; (b) compare the featural properties of the different surfaces in the display; and finally (c) interpret the information yielded by the first two processes in light of their configural knowledge. It seems plausible that, the more complex the surfaces used in a display, the less likely infants are to succeed in representing and comparing the surfaces. According to this account, the subjects of Schmidt et al. (1986) would thus have failed to segregate the displays they were shown, not because they lacked the configural knowledge necessary to correctly interpret the features of the displays, but because the displays themselves were too complex to be adequately encoded and compared; the segregation process was therefore stalled before it reached the interpretation stage, resulting in an ambiguous percept. Although it is not entirely clear what would make a display more or less complex for infants, our intuition is that many distinct factors, including the shape, pattern, and spatial arrangement of the surfaces in the display, are likely to contribute to its complexity.

The second inconsistency raised by the present data (see Figure 7) concerns the responses of the 4.5-month-olds in the similar condition and its replication, on the one hand, and of the 5-month-olds in the experiments by Craton (1993, 1996) and Spelke et al. (1993, similar condition), on the other. Recall that the infants in these experiments had ambiguous percepts of (a) similar partly occluded displays involving a rectangular box with jagged edges (Craton, 1993) or a surface with a

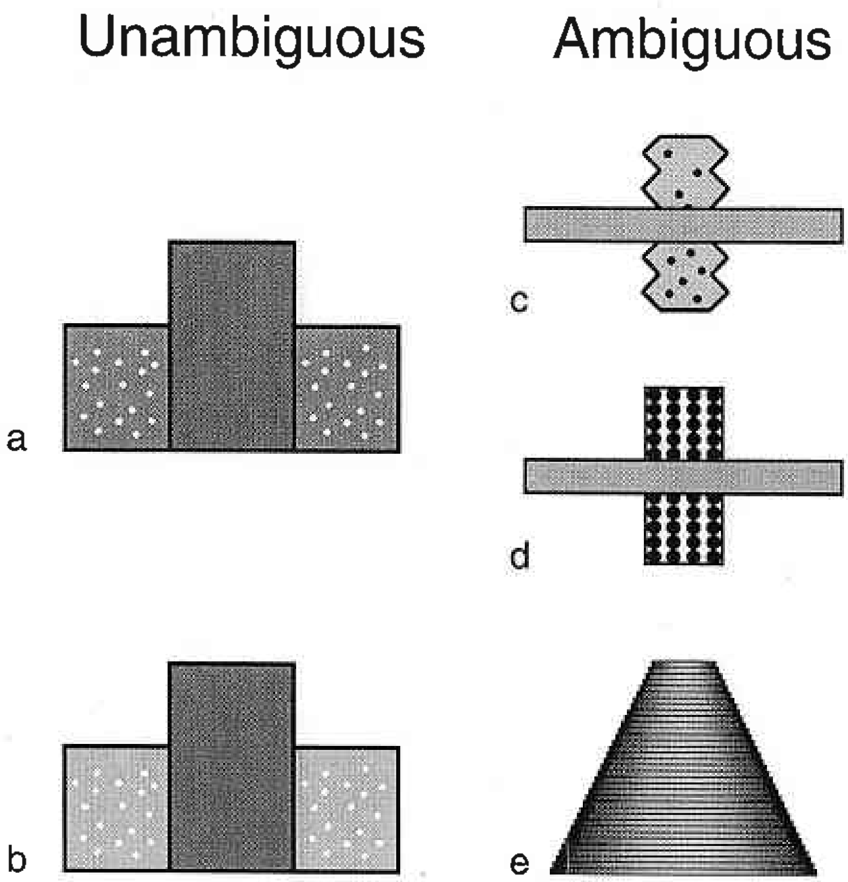

Fig. 7. Schematic drawing of the similar displays used in (A) Needham et al. (1997)—red boxes; (B) Needham et al. (1997)—light green boxes; (C) Craton (1993); (D) Craton (1996); and (E) Spelke et al. (1993).

large dot pattern (Craton, 1996), and (b) a similar adjacent display composed of multiple concentric rings (Spelke et al., 1993). Here again we suspect that the most likely explanation for these discrepant results has to do with the complexity of the displays used in the experiments. The similar displays in the present experiments involved simple shapes with smooth edges and a muted pattern. The displays used by Craton and by Spelke et al., on the other hand, presented edges or patterns that, though regular and symmetrical, were nevertheless composed of multiple salient elements. This added complexity could have made it more difficult for the infants

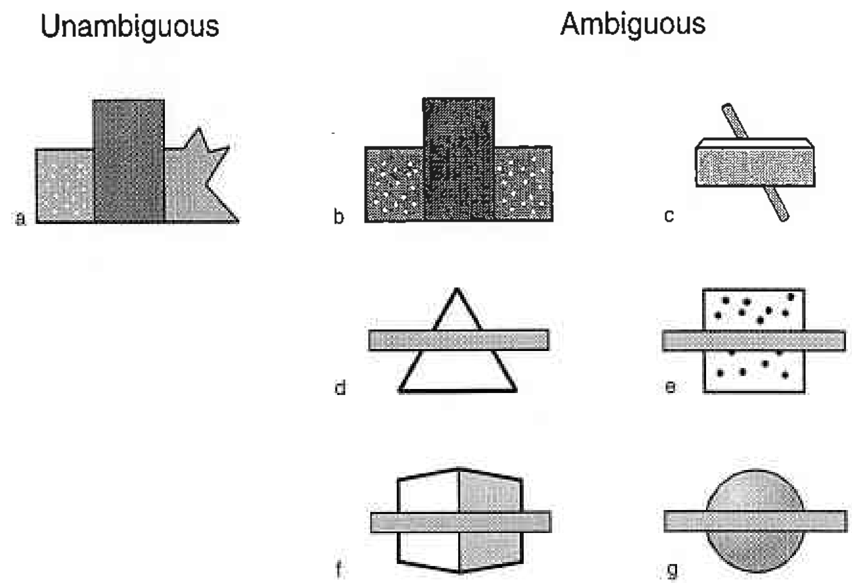

Fig. 8. Schematic drawing of the displays used in (A) and (B) Needham et al. (1997); (C) and (D) Kellman and Spelke (1983); (E) Termine et al. (1987); and (F) and (G) Schmidt and Spelke (1984).

to encode and compare the surfaces in the displays, thereby halting the segregation process and leading to ambiguous percepts.[1]

The third inconsistency raised by the present results (see Figure 8) has to do with the different responses of the 4-month-old infants in the similar and dissimilar conditions. Why were these young infants able to form an unambiguous interpretation of the dissimilar but not the similar display? This discrepancy was unlikely to reflect the relative complexity of the two displays, because the similar display could not plausibly be construed as being more complex than the dissimilar display. Indeed, the same is true of most of the similar displays used to explore 4-month-old infants' perception of partly occluded displays. The rod and triangle used by Kellman and Spelke (1983), the surface used by Termine et al. (1987), and the cube and sphere used by Schmidt and Spelke (1984) were all simple forms with smooth, fluid contours.

[1] One question that is raised by the present analysis is why the 5-month-old infants tested by Spelke et al. (1993) had an ambiguous perception of the similar but not the dissimilar display, since both displays were composed of multiple concentric rings (see Figure 3). One intriguing possibility is that, because of the marked differences in the shape and color of the two halves of the dissimilar display, the infants encoded the display in terms of these overall differences, paying little attention to the rings that made up each half.

If the 4-month-old infants could encode and compare the surfaces in both the similar and the dissimilar displays, why did they succeed in organizing the second but not the first display? At least two explanations were possible. The first was that the infants possessed the configural knowledge necessary to interpret the featural information in the dissimilar but not the similar display. That is, the infants had an expectation that dissimilar surfaces belong to distinct objects, but had not yet learned that similar surfaces typically belong to the same object. The second explanation was that, although the infants in the similar and the dissimilar conditions were equally capable of encoding, comparing, and interpreting the featural information before them, only the infants in the dissimilar condition attempted to do so. Perhaps the featural differences between the red and the green box were sufficiently salient to attract the infants' attention and activate their interpretation process, leading to an unambiguous percept. The featural similarities of the two red boxes, on the other hand, failed to engage the infants' interpretation process. The infants did not concern themselves during the familiarization trials with the issue of whether the red boxes formed one or two units; as a result, the infants had no interpretation that could be confirmed or disconfirmed by the move-apart or the move-together test event, and they therefore perceived neither event as surprising.[2]

One way to decide between the two explanations just described was to examine young infants' responses to adjacent as opposed to partly occluded displays. Evidence that young infants performed better with dissimilar than they did with similar adjacent displays would support the explanation that young infants possess configural expectations only about dissimilar surfaces. On the other hand, evidence that young infants succeeded with both types of adjacent displays would give weight to the notion that young infants have acquired configural knowledge about both similar and dissimilar surfaces, but do not at first make use of this knowledge in all contexts in which it is relevant. The results of our research with adjacent displays are described in the next section.

D. Experiments With Adjacent Displays

Our first experiment on young infants' perception of adjacent displays compared 4- and 4.5-month-old infants' responses to a similar and a dissimilar adjacent display (Needham, 1997). The infants assigned to the similar condition (see Figure 9) first received a familiarization trial during which they saw a stationary adjacent display composed of two arched boxes, each with a flat vertical edge (right edge for the left box, left edge for the right box) that allowed full contact between the boxes;

[2] It might be proposed that another explanation for 4-month-olds' consistent failure to organize similar partly occluded displays could be a reluctance to posit a hidden connection between the surfaces visible on either side of the occluder. However, data obtained with moving as opposed to stationary partly occluded displays make it clear that 4- and even 2-month-old infants will readily posit such hidden connections (e.g., Johnson & Nañez, in press; Kellman, Gleitman, & Spelke, 1987; Kellman & Spelke, 1983; Slater et al., 1990).

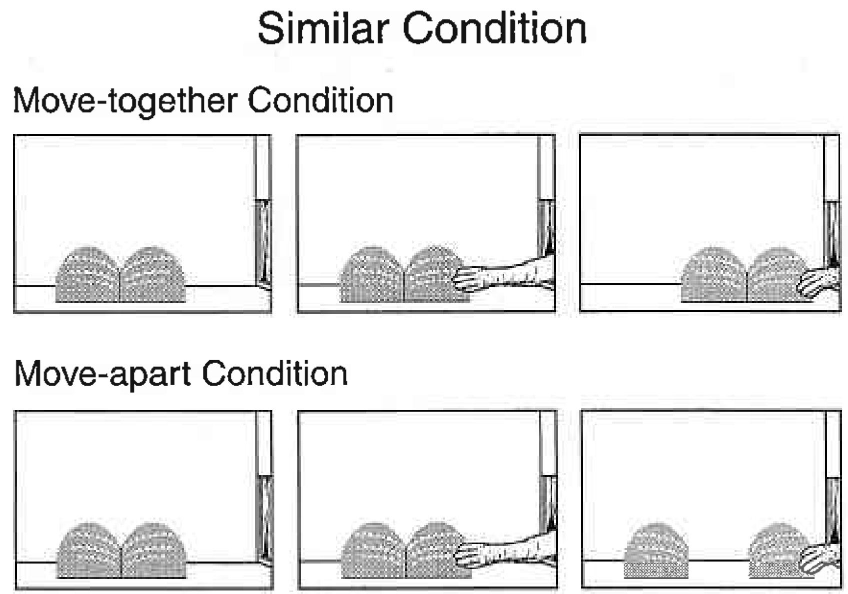

Fig. 9. Schematic drawing of the events shown to the infants in the similar condition in Needham (1997).

each box was made of red cardboard and was decorated with three thin black lines in a curved symmetric pattern centered at the boundary between the boxes. The infants in the dissimilar condition (see Figure 10) saw the same display except that the left box was rectangular in shape. After the familiarization trial, the infants saw a test event in which a gloved hand took hold of the right box and pulled it a short distance to the right. For half of the infants in each condition, the left box moved with the right box (move-together condition); for the other infants, the left box remained stationary throughout the event (move-apart condition).

We reasoned that if the infants were able to encode, compare, and interpret the featural information in the similar and the dissimilar display, then two predictions followed. First, the infants in the similar condition should expect the two arched boxes to move together, and they should be surprised in the move-apart event when only the right box moved. Second, the infants in the dissimilar condition should expect the rectangular box to remain stationary when the arched box was pulled, and they should be surprised in the move-together event when both boxes moved. Opposite patterns of looking were thus predicted for the infants in the similar and the dissimilar conditions.

Preliminary analyses of the data revealed no significant difference between the looking times of the 4- and 4.5-month-old infants; the data were therefore col-

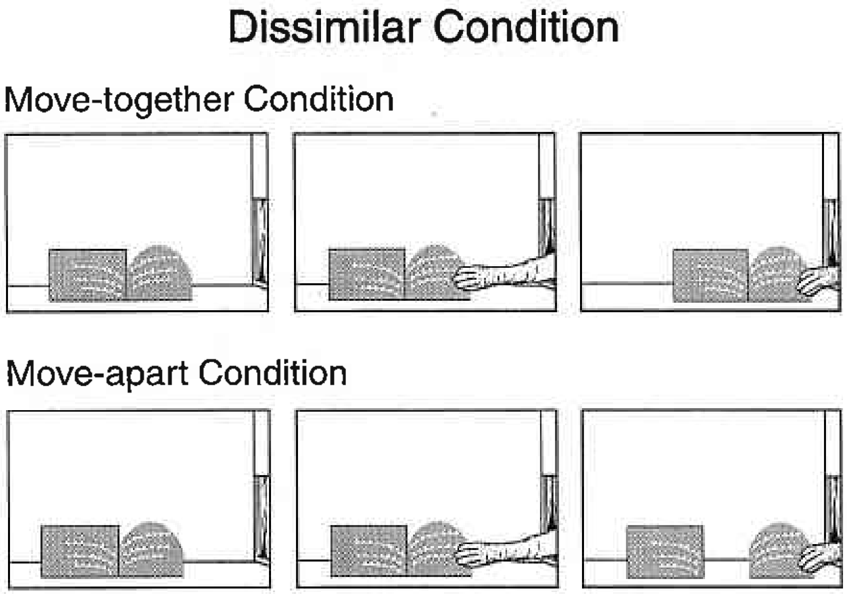

Fig. 10 Schematic drawing of the events shown to the infants in the dissimilar condition in Needham (1997a).

lapsed in subsequent analyses. Reliably different patterns of looking were observed in the two conditions. The infants in the similar condition looked reliably longer at the move-apart than they did at the move-together event, suggesting that they (a) were led by the featural similarities between the two arched boxes to group them into a single unit and thus (b) expected them to move together and were surprised when they did not. In contrast, the infants in the dissimilar condition showed a reliable preference for the move-together over the move-apart event, as though they (a) were led by the featural differences between the arched and the rectangular box to group them into distinct units and hence (b) expected the boxes to move independently and were surprised when they did not. Together, these results indicate that 4- and 4.5-month-old infants are able to organize both similar and dissimilar adjacent displays in accordance with their featural properties; we return at the end of the section to the implications of this finding for accounts of 4-month-old infants' persistent failure to organize similar partly occluded displays.

In addition to the experiment just described, we conducted another experiment examining 4.5-month-old infants' perception of a dissimilar adjacent display (Needham & Baillargeon, in press-a). This display was first used in experiments on the role of physical knowledge in 8-month-old infants' object segregation (Needham & Baillargeon, 1997; see Section V). Our initial intent had been to

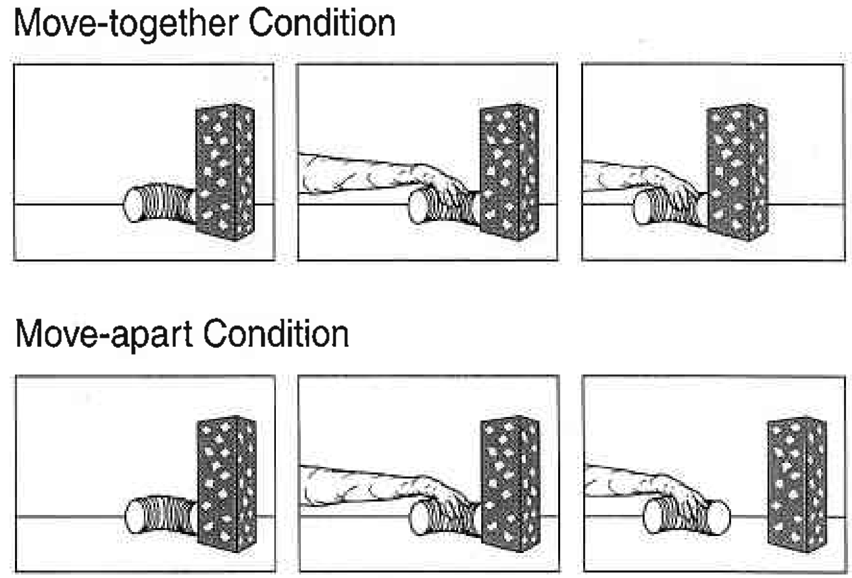

Fig. 11. Schematic drawing of the events shown to the infants in the cylinder-down condition in Needham and Baillargeon (in press-a).

extend this research to younger infants. As will soon become clear, however, our results led us in entirely new directions.

The infants 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 Figure 11). Next, the infants watched a test event in which a gloved hand took hold of the cylinder and pulled it a short distance to the left. For half of the infants, the cylinder and box moved together as one unit (move-together event); for the other infants, the cylinder moved apart from the box, which remained stationary throughout the event (move-apart event).

We reasoned that if the infants attended to the featural information in the display—as did the 4.5-month-olds in our previous experiments with dissimilar partly occluded (Needham et al., 1997) and adjacent (Needham, 1997) displays—then they should expect the box to remain stationary when the cylinder was pulled, and they should be surprised when the box and cylinder moved as a whole. The infants were thus expected to look reliably longer at the move-together than at the move-apart event.

Contrary to this expectation, however, the infants looked about equally at the two test events. These negative results suggested that the infants (a) were uncertain whether the cylinder and box constituted one or two units and hence (b) could not

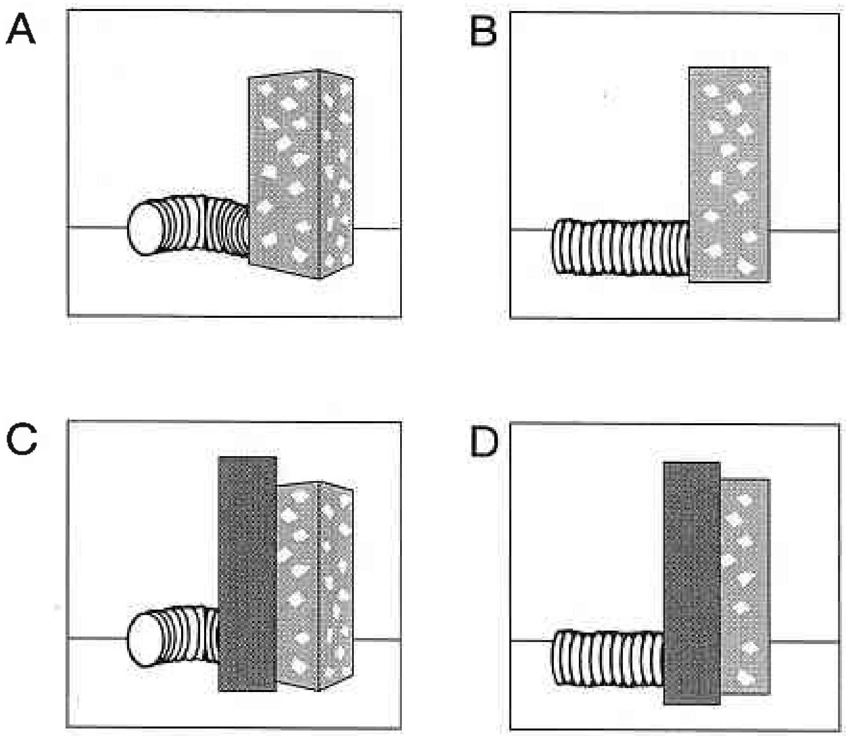

Fig. 12. Schematic drawing of the displays used in (12A) Needham and Baillargeon (in press-a); and (12B), (12C), and (12D) Needham (in press).

determine whether the cylinder should move with or without the box. In subsequent experiments (Needham, in press), 6.5- and 7.5-month-old infants were tested using the same procedure. Only the 7.5-month-old infants showed a reliable preference for the move-together over the move-apart event, suggesting that they perceived the cylinder and box as two distinct objects; like the 4.5-month-olds, the 6.5-month-olds tended to look equally at the two test events.

The results obtained with the 4.5- and 6.5-month-old infants in these experiments were inconsistent with our previous findings with dissimilar displays: Recall that 4- and 4.5-month-old infants correctly segregated a partly occluded display composed of a rectangular red box and an irregularly shaped green box (Needham et al., 1997), and an adjacent display composed of an arched and a rectangular red box (Needham, 1997). The most likely explanation for these discrepant results, we believed, was the one invoked in the last section to account for other

inconsistencies in 4.5-month-old infants' responses to displays. That is, we suspected that the 4.5- and 6.5-month-olds in the present experiments were unable to segregate the cylinder-and-box display because they had difficulty encoding and comparing the surfaces in the display. As can be seen in Figure 12A, the cylinder and box created a relatively complex set of surfaces. The cylinder was made of a section of clothes dryer vent hose that was stuffed and had its ends bent slightly forward, giving rise to a complex zigzag-edged, curved shape. In addition, the boundary between the cylinder and box did not simply consist of two surfaces parallel to the infants' line of sight; instead, one of the box's corners faced the infants, and the right end of the cylinder lay behind and was partly occluded by the box's left rear wall. These factors could have made it difficult for the infants to complete their analysis of the display's spatial and featural properties, thereby stalling the segregation process before it reached the interpretation stage and resulting in an indeterminate percept of the display.

To explore whether the complexity of the cylinder-and-box display had contributed to the 4.5- and 6.5-month-olds' ambiguous response, additional infants at each age were tested with a "simplified" version of the display (Needham, in press). In this simplified display (see Figure 12B), (a) a straight rather than a curved cylinder was used; (b) the box was positioned so that one of its sides rather than one of its corners faced the infant; (c) the connection between the cylinder and box was parallel to the infants' line of sight; and finally (d) the front of the cylinder and box were aligned. Both the 4.5- and the 6.5-month-old infants tested with the simplified display looked reliably longer at the move-together than at the move-apart event, suggesting that they viewed the simplified version of the cylinder-and-box display as composed of two distinct units.

To confirm the discrepancy between infants' perception of the original and the simplified cylinder-and-box display, an additional experiment was conducted comparing 4.5-month-old infants' responses to the same two displays, but now partly occluded. The infants saw either the original or the simplified display with a tall, narrow screen occluding the boundary between the cylinder and box (see Figures 12C and 12D). The results indicated that the infants who saw the original display tended to look equally at the test events, whereas the infants who saw the simplified display showed a reliable preference for the move-together over the move-apart event. These results were identical to those obtained with the adjacent displays and confirmed that the infants (a) had an indeterminate perception of the original cylinder-and-box display, but (b) had an unambiguous perception of the simplified display as composed of two units.

Together, the results of the experiments presented in this section point to three conclusions. First, the results provide further evidence for the conclusion, first suggested by our experiments with partly occluded displays (Needham et al., 1997), that even young infants possess configural knowledge. The 4- and 4.5-month-old infants in the present experiments who were tested with the similar or the dissimilar adjacent display (Needham, 1997), and with the adjacent or the

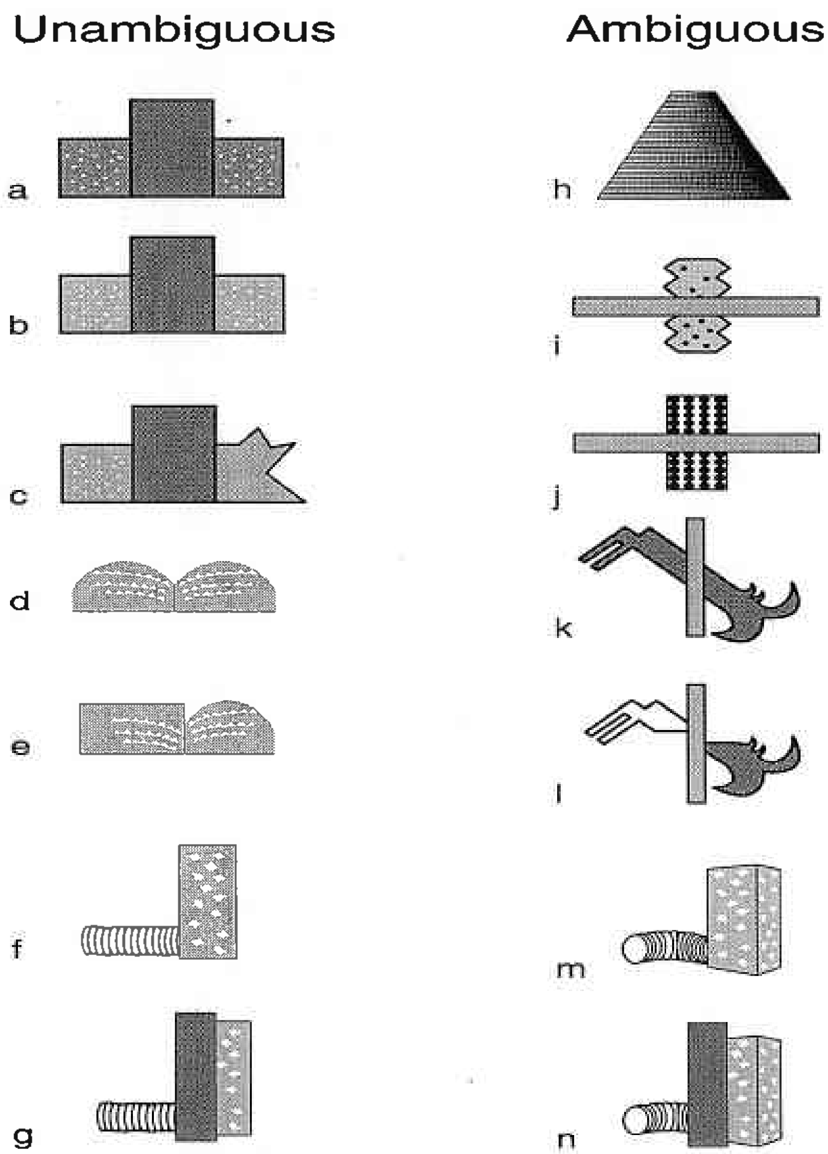

Fig. 13. Schematic drawing of the displays used in (a) Needham et al. (1997)—red boxes; (b) Needham et al. (1997)—light green boxes; (c) Needham et al. (1997); (d) and (e) Needham (1997); (f) and (g) Needham (in press); (h) Spelke et al. (1993); (i) Craton (1993); (j) Craton (1996); (k) and (l) Schmidt et al. (1986); (m) Needham and Baillargeon (in press-a); and (n) Needham (in press).

partly occluded simplified cylinder-and-box display (Needham, in press) all gave clear evidence that they expected similar but not dissimilar surfaces to belong to the same unit.

Second, the present results lend strong support to the notion, first advanced in the previous section, that whether infants aged 4.5 months and older form an ambiguous or an unambiguous percept of a display critically depends on the display's complexity. In the present experiments, 4.5- and 6.5-month-old infants were found to be unable to parse the original cylinder-and-box display; however, 4.5-month-old infants readily succeeded in segregating a simplified version of the same display presented in either an adjacent or a partly occluded format (Needham, in press). These findings underscore the context sensitivity of young infants' segregation ability. Even relatively modest changes in displays can have a dramatic effect on infants' success at segregating the displays. Figure 13 summarizes the displays known to result in unambiguous interpretations at 4.5 months of age (Figure 13A) and in ambiguous responses at 4.5 or 5 months (Figure 13B).

Finally, the results obtained with the 4-month-old infants tested with the similar adjacent display (Needham, 1997) bear on the two explanations proposed in the last section for young infants' inability to organize similar as opposed to dissimilar partly occluded displays (e.g., Kellman & Spelke, 1983; Needham et al., 1997; Schmidt & Spelke, 1984; Termine et al., 1987). The present results argue against the first of these explanations, which was that young infants lack configural expectations about similar surfaces. This leaves open the second explanation, which was that 4-month-old infants have difficulty with similar partly occluded displays because the featural similarity of the surfaces on either side of the occluder is not sufficiently salient to attract the infants' attention and engage their interpretation process. The finding that 4-month-old infants perform better with similar adjacent as opposed to partly occluded displays could be taken to support this explanation. Infants might be more likely to notice featural similarities in surfaces that are separated by a boundary than in surfaces that are separated by an occluder. Similar adjacent displays would thus be better designed to highlight the featural similarity of surfaces and thus activate young infants' interpretation process, leading to unambiguous percepts.

E. Future Directions

The research reported in the last two sections indicates that, contrary to earlier claims (e.g., Kellman & Spelke, 1983; Spelke, 1982, 1985a, 1991), young infants possess configural knowledge and expect similar but not dissimilar surfaces to belong to the same units. Interestingly, this characterization of young infants' approach to three-dimensional displays is very much in line with reports over the past two decades of sophisticated perceptual organization in young infants' responses to two-dimensional displays (e.g., Bornstein & Krinsky, 1985; Colombo, Laurie, Martelli, & Hartig, 1984; Ghim, 1990; Ghim & Eimas, 1988;

Giffen & Haith, 1984; Milewski, 1979; Quinn, Burke, & Rush, 1993; Quinn & Eimas, 1986; Salapatek, 1975; Slater, 1989; Treiber & Wilcox, 1980). For example, Quinn et al. (1993) familiarized 3-month-old infants with a display consisting of a 4 x 4 square grid of light and dark elements arranged in either rows (row display) or columns (column display). Next, the infants saw test displays consisting of horizontal or vertical stripes. The authors reasoned that if the infants grouped the elements in the familiarization displays on the basis of their lightness, then the row display should be viewed as resembling the horizontal-stripe display, and the column display the vertical-stripe display. The results indicated that the infants who were familiarized with the row display looked reliably longer at the vertical- than at the horizontal-stripe display, whereas the infants who were familiarized with the column display showed the reverse looking pattern. These results suggested that the infants were sensitive to the lightness of the elements in the familiarization displays and used this information to organize the elements into larger units.

The conclusion that young infants are capable of sophisticated perceptual organization when presented not only with two- but also with three-dimensional displays opens many new directions for future research. One such direction concerns the nature of infants' configural knowledge. We need to specify precisely what featural and spatial information infants attend to when judging whether surfaces are similar or dissimilar, and how this information changes with age. In particular, do infants consider the alignment, shape, pattern, color, and texture of surfaces from the start, or do they come to use these variables one by one over a period of weeks or months (as has been found in other areas of infants' knowledge about objects; see Baillargeon, 1994, 1995)? If the latter, in what sequence do infants identify the variables, and what mechanisms are responsible for their identification?

Another direction for future research concerns the origins rather than the development of young infants' configural knowledge. The evidence presented in the previous sections suggests that, by 4 months of age, infants already possess configural expectations about objects. There is reason to believe that younger infants lack such expectations, and rely exclusively on spatial continuity/discontinuity information to organize displays. Using a variety of experimental procedures, Spelke and her colleagues (e.g., Kestenbaum, Termine, & Spelke, 1987; Prather & Spelke, 1982; Spelke et al., 1993) have examined 3-month-olds' perceptions of stationary adjacent displays. The results of these experiments have consistently shown that infants this age view spatially continuous surfaces, whether similar or dissimilar, as belonging to the same units.[3] To date, no investigation has focused on 3-month-olds' responses to stationary partly occluded displays. However, experiments by Slater and his collaborators (e.g., Slater et al., 1990, 1994) have repeatedly found that newborn infants view surfaces visible on either side of an occluder, even when similar and moving in perfect synchrony, as belonging to separate units. Together, these data tentatively suggest that infants begin by grouping spatially continuous surfaces into the same unit and spatially discontinuous surfaces into distinct units. Between 3 and 4 months of age, perhaps as a result of marked improvements in their visual abilities (e.g., Banks, 1983; Yonas & Granrud, 1984), infants would become aware of the limitations of their initial rule and would begin to consider featural information when organizing displays. Experiments are needed to test these speculations and more generally to determine the origins of object segregation in infancy.

[3]In a number of experiments, Spelke and her colleagues examined 5-month-old infants' responses to adjacent displays using a reaching method (e.g., Hofsten & Spelke, 1985; Spelke, Hofsten, & Kestenbaum, 1989). Interestingly, the results obtained with this method were more similar to those found with the 3- than with the 5-month-olds in Spelke's preferential-looking experiments (e.g., Kestenbaum et al., 1987; Prather & Spelke, 1982; Spelke et al., 1993). These results might be taken as further evidence of the oft-noted discrepancy between action and nonaction assessments of infants' perceptual and cognitive abilities (e.g., Baillargeon, 1993; Spelke, 1994).

IV. INFANTS' USE OF EXPERIENTIAL KNOWLEDGE

We argued earlier (see section II) that adults bring to bear not only their configural but also their experiential knowledge when segregating displays. Do infants, like adults, use information gained in prior experiences with objects to organize displays containing the same or similar objects? A preliminary experiment by Schwartz (1982) suggested that the answer to this question might be positive. Schwartz found that 5-month-old infants who were habituated to a slide depicting a partly occluded human face looked reliably longer during test at an incomplete than at a complete version of the face. These data suggested that infants use their knowledge about familiar objects such as faces when organizing stationary partly occluded displays. The research described in this section was designed to extend this result in two directions. First, it focused on infants' segregation of adjacent rather than partly occluded displays. Second, it examined infants' use of experiential knowledge gained in very brief encounters with objects as opposed to knowledge (such as knowledge of faces) acquired through long-standing and extensive interactions with objects.

A. Experiments With Adjacent Displays

The point of departure of our research on young infants' use of experiential knowledge was the finding obtained with the 4.5-month-old infants who were tested with the original cylinder-and-box display (Needham & Baillargeon, in press-a). Recall that these infants tended to look equally at the move-together and the move-apart test events, as though they were unsure whether the cylinder and box formed one or two units. Our interpretation of this finding was that, because of the complexity of the display, the infants had difficulty representing or encoding the surfaces in the display; as a result, the segregation process was stalled before the interpretation stage, preventing the infants from applying their configural

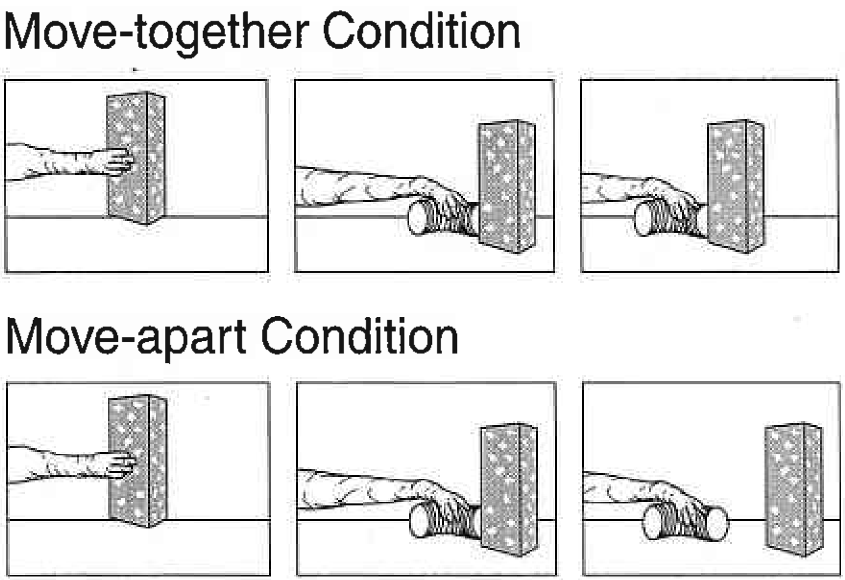

Fig. 14. Schematic drawing of the events shown to the infants familiarized with only the box in Needham and Baillargeon (in press-a).

knowledge. In a subsequent experiment (Needham, in-press), 4.5-month-old infants were tested with a simplified version of the cylinder-and-box display, one designed to be easier to encode; the infants in this experiment looked reliably longer at the move-together than at the move-apart event, suggesting that they (a) were now able to represent and compare the cylinder and box and (b) interpreted the featural differences between them as signaling two distinct objects.

In the present research (Needham & Baillargeon, in press-a), we explored an alternative way of facilitating young infants' segregation of the original cylinder-and-box display. Instead of realigning the cylinder and box so that they presented a simpler arrangement of surfaces, we adopted a different approach: We exposed the infants the box alone before presenting them with the entire display. We reasoned that if the infants (a) recognized the box when shown the cylinder-and-box display and (b) were able to use this information to segregate the display, then they should view it as comprising two distinct objects, the familiar box and the unfamiliar cylinder. Giving the infants a prior exposure to the box thus provided them with an alternative means of segregating the display. Instead of representing, comparing, and interpreting the featural information in the display, to determine how many objects it contained, the infants could focus from the start on what familiar and unfamiliar objects were present in the display. In other words, the infants

could make use of their experiential rather than their configural knowledge to organize the display.

As in our initial experiment with the cylinder-and-box display, 4.5-month-old infants received one familiarization trial followed by six test trials in which they saw either the move-apart or the move-together test event. The only difference between the two experiments had to do with the familiarization trial. Whereas the infants in the first experiment were shown the entire cylinder-and-box display, for a period of 10 to 30 s (mean looking time was 17.5 s), the infants in the present experiment were shown only the box, for a period of 5 s (see Figure 14). An experimenter held the box above the apparatus floor and tilted it alternately to the right and to the left until the computer signaled that the infant had cumulated 5 s of looking at the box.

The design of this experiment was thus predicated on two assumptions. The first was that the infants would be able to recognize the box after seeing it for only a brief (5-s) exposure, and the second was that the infants would readily make use of this information to organize the cylinder-and-box display. How plausible were these assumptions?

Young infants' visual recognition memory is remarkably robust. By 5 months of age, infants are capable of recognizing previously experienced stimuli on the basis of modest amounts of familiarization and over appreciable retention intervals (e.g., Cornell, 1979; Fagan, 1973; Martin, 1975). To illustrate, Fagan (1973) showed 5-month-old infants a photograph of a face for 2 min. After delays of 3 hours and 1, 2, 7, and 14 days, the infants were presented with the familiar face paired with a novel face. At all intervals, the infants looked reliably longer at the novel than at the familiar face. In another experiment, Fagan (1974) examined how much familiarization time 5-month-olds required to recognize various stimuli on immediate as opposed to delayed tests. He found that, whereas 20 to 30 s of familiarization time were needed for faces, and 17 s for abstract patterns composed of identical elements, as little as 4 s were necessary for stimuli varying along several dimensions. Given these and other similar findings (e.g., Cornell, 1979; Fagan, 1977; Lasky, 1980; Rose, 1980, 1981), it seemed probable that a 5-s familiarization time would be sufficient to enable the infants to recognize the box in the test trials.

If the infants did recognize the box in the test trials, how likely were they to use this information to segregate the cylinder-and-box display? Recent research suggests that infants' prior encounters with objects do affect their subsequent perceptions of the objects (e.g., Granrud, Haake, & Yonas, 1985; Yonas, Pettersen, & Granrud, 1982). For example, Granrud et al. (1985) gave 7-month-old infants a large and a small novel object to play with for a 10-min familiarization phase. During the test phase, the infants were presented with two objects: the large object, and a version of the small object enlarged to be of the same size as the large object. The two objects were positioned at the same distance from the infants, who were allowed to reach for them. Under monocular viewing conditions, the infants

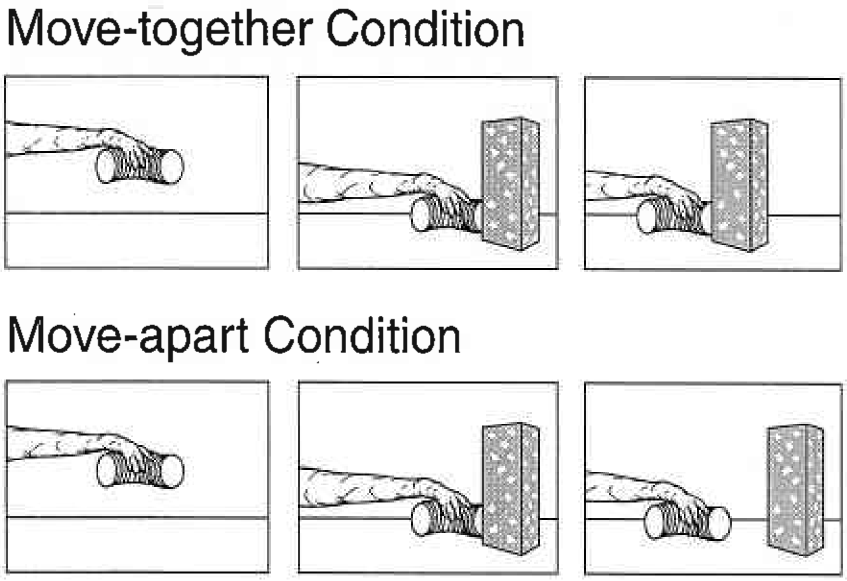

Fig. 15. Schematic drawing of the events shown to the infants familiarized with only the cylinder in Needham and Baillargeon (in press-a).

reached reliably more toward the previously small object, suggesting that they perceived it to be nearer than the large object. These and other data indicated that the infants brought to bear their knowledge of the objects' sizes—acquired during the familiarization phase—when estimating their distances.

Given all of this evidence, it seemed reasonable to expect that the infants might be able to use their brief experience with the box to segregate the cylinder-and-box display. The results supported this expectation: The infants looked reliably longer at the move-together than at the move-apart event, suggesting that they (a) recognized the box when it stood next to the cylinder; (b) inferred, based on this information, that the box and cylinder were separate units; and hence (c) expected the two to move independently and were surprised in the move-together event that they did not. These results contrasted with those of our initial experiment and indicated that being familiarized with the box alone, rather than with the entire display, made it possible for the infants to achieve an unambiguous interpretation of the display.

The results of this last experiment suggested that, by 4.5 months of age, infants are able to use their prior knowledge of an object to segregate an adjacent display containing the object. In an attempt to confirm this finding, we conducted another experiment that was identical to the last except that the infants were exposed to the

cylinder rather than the box during the familiarization trial (see Figure 15). Unlike the infants who were familiarized with the box alone, the infants familiarized with the cylinder alone tended to looked equally at the move-together and the move-apart events, suggesting that their perception of the cylinder-and-box display was indeterminate.

How could one explain the discrepant responses of the infants exposed to the box alone and to the cylinder alone? One hypothesis was suggested by the evidence, mentioned earlier, that more complex stimuli typically require more time to encode than simpler stimuli (e.g., Fagan, 1974, 1977; Rose & Slater, 1983). It seemed possible that, because the cylinder was more complex than the box, a 5-s exposure to the cylinder did not give the infants sufficient time to familiarize themselves with it; as a result, they failed to recognize it when shown the cylinder-and-box display and hence had no experiential knowledge they could use to parse the display.

This analysis predicted that infants' performance should improve following a longer exposure to the cylinder. Our next experiment sought to test this prediction: The infants were exposed to the cylinder for 15 rather than for 5 cumulative seconds during the familiarization trial. The infants now looked reliably longer at the move-together than at the move-apart event, suggesting that they (a) viewed the cylinder and box as distinct units and hence (b) expected them to move separately and were surprised when this expectation was violated.

These results, like those obtained with the infants who were familiarized with the box alone, indicate that 4.5-month-old infants bring to bear prior experiences with objects when segregating displays involving the objects. Such a finding suggests that young infants possess a valuable tool for organizing their daily world. According to the present results, an infant who recognizes a rattle standing next to an unfamiliar cup, shoe, or whistle should be able to determine the boundaries of these novel objects because she already knows the boundaries of the rattle. Through this sort of "experiential bootstrapping," young infants' experiential knowledge could considerably facilitate their parsing of scenes containing familiar and novel objects.

Our final experiment began to explore the conditions under which young infants are able to use their experiential knowledge for segregation purposes. Of particular interest were effects of context and delay. Could infants make use of a prior experience with an object to organize a display containing the object, even if they viewed the display in a different context than the object, and after a delay? To return to our previous example, would an infant be able to use her knowledge of a rattle to segregate it from a cup, even if she saw the rattle-cup display in a different setting and at a later time than the rattle?

The infants in this experiment were familiarized with the box in their own homes about 24 hours before they were scheduled to be tested in the lab; an experimenter drove to the infants' homes and showed them the box for 2 min. Sessions in the lab began directly with the test trials; the infants saw either the move-together or the move-apart event, as before, for six test trials. Reliably different looking patterns were found in the first three and last three test trials. During the first block of trials, the infants tended to look equally at the move-together and the move-apart events; during the second block, the infants looked reliably longer at the move-together than at the move-apart event. These results suggested that, although the infants did not immediately recognize the box upon seeing it, they did so after a few trials (since the infants had not seen the box for 24 hours, and they were encountering it in an entirely novel setting, this finding did not seem very surprising). After recognition emerged, the infants (a) inferred that the box and cylinder were distinct objects and therefore (b) expected them to move independently and were surprised when they did not.

The results summarized in this section point to three conclusions. The first is that, by 4.5 months of age, infants bring to bear their experiential knowledge when segregating displays. The infants who, when shown the cylinder-and-box display, recognized the box or cylinder they had seen during the familiarization trial readily segregated the display into two distinct units. These results, together with those reported in section III, indicate that 4.5-month-old infants can use two of the same types of object knowledge as adults—configural and experiential knowledge—when organizing displays.

The second conclusion suggested by the present results is that young infants' use of experiential knowledge does more than simply provide them with an alternative route to segregating displays: It also makes it possible for them to deal successfully with displays they could not otherwise segregate. We saw earlier (Section III) that, when faced with complex displays, young infants are often unable to complete their analysis of the displays' featural properties; the segregation process thus becomes stalled before infants can bring their configural knowledge to bear. Fortunately, young infants' ability to use experiential knowledge gives them another way to approach complex displays. Recall that the 4.5-month-old infants in our initial experiment with the cylinder-and-box display were unable to encode and compare the complex arrangement of surfaces in the display and hence could not form a clear interpretation of the display. However, after being exposed to the box alone (for 5 s) or to the cylinder alone (for 15 s), the infants readily succeeded in parsing the display. Instead of a configural approach—encoding, comparing, and interpreting the features of the cylinder and box—the infants were able to adopt an easier, experiential approach and segregate the display into a familiar and an unfamiliar object.

The third conclusion that can be drawn from the present data concerns the remarkable robustness of young infants' ability to use experiential knowledge. The results indicate that, to be of help to infants, a prior experience with an object does not have to be extensive, nor does it have to occur in the same setting as or immediately preceding infants' exposure to the test display containing the object. All that matters for a prior experience to be effective is that infants be able to encode sufficient information about the object to recognize it when they next encounter it in the test display. In the present experiments, exposures of as little as 5 s for the box and 15 s for the cylinder were sufficient to ensure recognition—and hence a successful segregation performance—when the test trials immediately followed the familiarization trial. Although it is doubtful whether such brief exposures would have been adequate when the test trials were delayed by 24 hours (e.g., Cornell, 1979), as in our last experiment, even then a comparatively brief 2-min exposure proved adequate for the task. Such a finding, incidentally, confirms Fagan's (1973) results: Recall that 5-month-old infants who were familiarized with a face for 2 min were able to recognize the face after delays of 1 day or more.

B. Future Directions

The finding that young infants are capable of using their experiential knowledge for segregation purposes suggests several directions for future research. One such direction is whether infants' interpretation of a display would be affected by prior exposure to an object similar but not identical to an object in the display. To illustrate, would 4.5-month-old infants correctly parse the cylinder-and-box display after being familiarized with a box that shared some, but not all, of the features of the test box (e.g., a familiarization box of the same size and shape as the test box, but of a different color and pattern)? Preliminary evidence collected in Needham's laboratory suggests that young infants are very selective in their use of experiential knowledge and benefit from a prior exposure to an object that is highly similar, but not moderately or weakly similar, to the test object.

Such evidence, if valid, could lead to investigations of prior exposures involving not single objects, as has been the case so far, but rather object categories. Let us assume, for example, that infants are found not to benefit from being exposed to a tall red, green, or purple box before seeing the tall blue box in the cylinder-and-box display. Would infants nevertheless be helped by being exposed to all three familiarization boxes before seeing the display? Could infants, in other words, categorize the familiarization boxes on the basis of their common perceptual features, and then use this same category information to parse the cylinder-and-box display? Recent evidence indicates that such perceptual categorization responses fall well within the range of young infants' ability (e.g., Eimas & Quinn, 1994; Quinn & Eimas, 1996). In one experiment, for example, Eimas and Quinn (1994) familiarized 3- and 4-month-old infants with color photographs of horses. During the test trials, the infants saw photographs of novel horses paired with cats, zebras, or giraffes. The infants reliably preferred the cats, zebras, and giraffes over the novel horses, suggesting that they had formed a categorical representation for horses during the familiarization trials. It will be interesting to find out whether young infants' use of experiential knowledge in segregation tasks is limited to representations of particular objects or whether it extends, under some conditions at least, to representations of entire object categories.

V. INFANTS' USE OF PHYSICAL KNOWLEDGE

We proposed earlier (see Section III) that adults use physical as well as configural and experiential knowledge when segregating displays. Recent evidence indicates that young infants possess many intuitions about objects' displacements and interactions with other objects (e.g., see Baillargeon, 1993, 1994, 1995; Baillargeon et al., 1995; Spelke, 1994; and Spelke et al., 1992, for recent reviews). The two experiments described in this section began to examine whether young infants, like adults, bring to bear their physical knowledge when organizing displays. The first experiment focused on infants' understanding of support, and the second experiment, on infants' understanding of impenetrability.

A. Experiment Involving Infants' Intuitions About Support

There is growing evidence that young infants possess intuitions about support relations between objects (Baillargeon, Needham, & DeVos, 1992; Baillargeon, Raschke, & Needham, 1997; Needham & Baillargeon, 1993; see Baillargeon, 1994, 1995, and Baillargeon et al., 1995, for reviews). One experiment, for example, examined whether 4.5- and 5.5-month-old infants realize that objects are

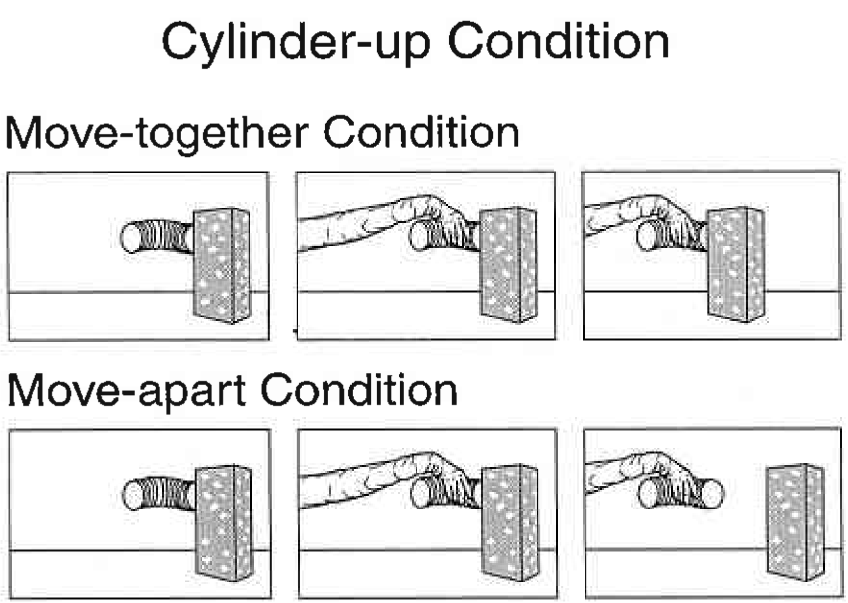

Fig. 16. Schematic drawing of the events shown to the infants in the cylinder-up condition in Needham and Baillargeon (1997).

unstable when released against vertical surfaces (Baillargeon et al., 1997). 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 this 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 results revealed that the 5.5- and even some of the 4.5-month-old infants looked reliably longer at the impossible than at the possible event, suggesting 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 this and other (Baillargeon et al., 1992; Needham & Baillargeon, 1993) demonstrations that young infants possess knowledge about support, it seemed plausible to ask whether they would make use of this knowledge when parsing displays. The point of departure for this research was the finding (Needham, in press), reported earlier, that 7.5-month-old infants who are shown the cylinder-and-box display perceive this display to be composed of two distinct parts. The question investigated in our first experiment (Needham & Baillargeon, in press-b) was how infants would respond if the cylinder was raised above the apparatus floor so that it made contact with the upper rather than the lower portion of the box. Would infants, based on their knowledge of support, (a) realize that the suspended cylinder could not remain stable if it were merely resting against the box, and hence (b) conclude that the cylinder must be attached to the box?

Subjects were 8-month-old infants. The infants were randomly assigned to one of two conditions: the cylinder-down or the cylinder-up condition (see Figures 11 and 16). The infants in the cylinder-down condition saw the same familiarization display and move-together or move-apart test events as the 7.5-month-olds in our earlier experiment (Needham, in press). The infants in the cylinder-up condition received similar familiarization and test trials except that the cylinder was suspended above the apparatus floor and contacted the upper portion of the box.

We fully expected that, like the 7.5-month-olds before them (Needham, in press), the infants in the cylinder-down condition would (a) be led by the featural differences between the cylinder and box to view them as distinct units and hence (b) would expect them to move independently and be surprised in the move-together event when they did not. The question of interest concerned the performance of the infants in the cylinder-up condition. Our reasoning was that if these infants (a) understood, based on their knowledge of support, that the cylinder must be attached to the box and (b) allowed the interpretation dictated by their physical knowledge (one unit) to supersede that suggested by their configural knowledge (two units), then they should expect the cylinder and box to move together and be surprised in the move-apart event when they did not.

The infants in the cylinder-down condition looked reliably longer at the move-together than at the move-apart event, suggesting that they viewed the cylinder-and-box display as composed of two separate units. This result confirmed our earlier result with 7.5-month-olds (Needham, in press) and suggests that infants this age, unlike 4.5- and 6.5-month-old infants (Needham, in press; Needham & Baillargeon, in press-a), are readily able to encode, compare, and interpret the featural differences between the cylinder and box.

In contrast to the infants in the cylinder-down condition, the infants in the cylinder-up condition looked reliably longer at the move-apart than at the move-together event, suggesting that they perceived the cylinder and box as constituting a single unit. This finding indicates that, by 8 months of age, infants bring to bear their physical knowledge—in this case, their knowledge of support—in making decisions about the composition of displays. The present result also suggests that, when confronted with conflicting interpretations of a display, one based on their configural knowledge and the other on their physical knowledge, 8-month-olds allow the second interpretation to override the first. The infants in the cylinder-up condition judged that the cylinder and box formed a single unit even though the two presented the same marked featural dissimilarities as in the cylinder-down condition, where the cylinder and box were seen as distinct units.

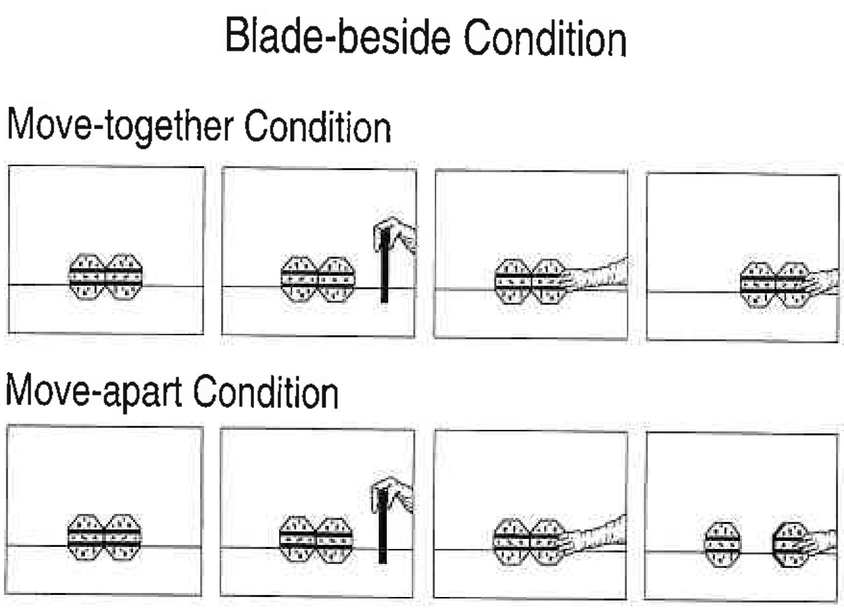

Fig. 17. Schematic drawing of the events shown to the infants in the blade-beside condition in Needham and Baillargeon (1997).

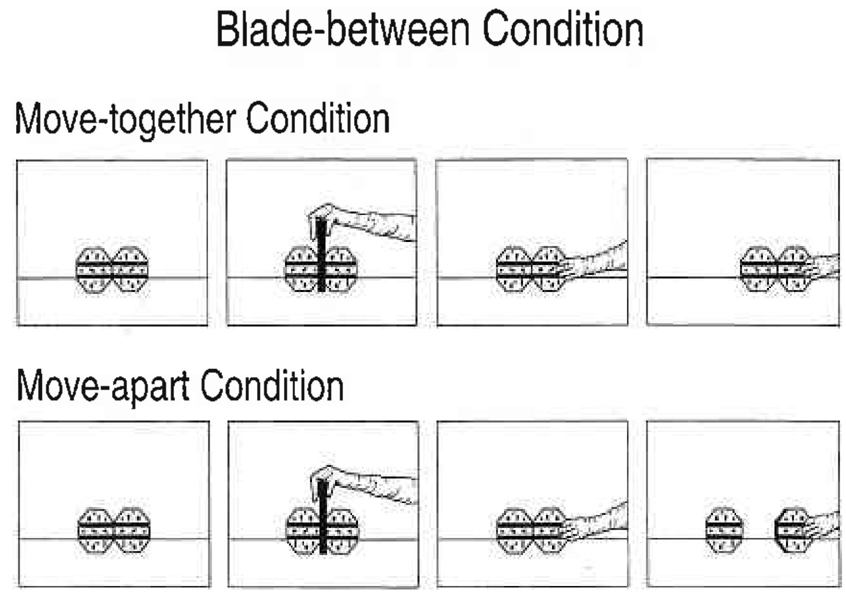

Fig. 18. Schematic drawing of the events shown to the infants in the blade-between condition in Needham and Baillargeon (1997).

B. Experiment Involving Infants' Intuitions About Impenetrability

The experiment described in the last section indicated that 8-month-old infants, like adults, bring to bear their knowledge of support when organizing a display. To confirm and extend this finding, a second experiment was conducted that tested whether infants' organization of a display would also be affected by their intuitions about impenetrability (Needham & Baillargeon, 1997).

There is a large body of evidence demonstrating that even very young infants recognize that one object cannot pass through the space occupied by another object (e.g., Baillargeon, 1987, 1991; Baillargeon & DeVos, 1991; Baillargeon, Graber, DeVos, & Black, 1990; Baillargeon, Spelke, & Wasserman, 1985; Spelke et al., 1992). For example, Spelke et al. (1992) habituated 2.5-month-old infants to an event in which a ball rolled from left to right along a platform and disappeared behind a screen. Next, the screen was removed to reveal the ball resting at the end of the platform. Following habituation, the infants saw a possible and an impossible test event. These events were similar to the habituation event except that a tall, thin box stood behind and protruded above the screen. At the end of the possible event, the screen was removed to reveal the ball resting against the box. At the end of the impossible event, the screen was removed to reveal the ball resting at the end of the platform, as in the habituation event. The infants looked reliably longer at the impossible than at the possible event, suggesting that they (a) understood that the ball could not roll through the space occupied by the box and hence (b) were surprised in the impossible event when the ball was revealed on the far side of the box.

In light of the above results, it seemed reasonable to ask whether 8-month-old infants could bring to bear their intuitions about impenetrability when organizing displays. A secondary goal of the research was to obtain further evidence that infants this age are able to organize adjacent displays in accordance with their featural properties.

The infants first received a familiarization trial in which they saw a stationary, adjacent display consisting of two identical yellow octagons decorated with blue dots and stripes (see Figures 17 and 18). 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 deg (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 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).

We reasoned that if the infants in the blade-beside condition were led by the featural similarity of the octagons to view them as a single unit, then they should expect the octagons to move jointly and be surprised in the move-apart event when this expectation was violated. In addition, if the infants in the blade-between condition (a) realized that, because the blade could be inserted between the octagons, the two could not constitute a single unit, and (b) gave more importance to the interpretation suggested by their knowledge of impenetrability (two units) than to the interpretation suggested by their configural knowledge (one unit), then they should expect the octagons to move independently and be surprised in the move-together event when they did not.

The infants in the blade-beside condition looked reliably longer at the move-apart than at the move-together event, suggesting that they perceived the octagons as one cohesive unit. This result, together with the results of the previous experiment (Needham & Baillargeon, 1997), provide clear evidence that 8-month-old infants possess configural knowledge and expect similar surfaces (such as those of the octagons) to belong to the same unit and dissimilar surfaces (such as those of the cylinder and box) to belong to distinct units. Such a conclusion is of course consistent with the findings reported earlier on 4- and 4.5-month-olds' perception of similar and dissimilar adjacent displays (Needham, 1997; see Section III).

In contrast to the infants in the blade-beside condition, the infants in the blade-between condition looked reliably longer at the move-together than at the move-apart event, suggesting that they viewed the octagons as two separate units. This finding extends the results of our previous experiment (Needham & Baillargeon, 1997) and indicates that 8-month-old infants bring to bear their intuitions about impenetrability as well as support when segregating displays. Finally, the present result also confirms our previous conclusion that, when faced with two conflicting interpretations of a display, one suggested by their configural knowledge and the other 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 exactly the same display—and hence exactly the same featural information—as the infants in the blade-beside condition. Nevertheless, the infants in the blade-between condition judged that the octagons constituted two rather than one unit.

C. Future Directions

The results of the two experiments presented in this section indicate that, at 8 months of age, infants' organization of a novel display is affected not only by the featural properties of the surfaces in the display, but also by their physical properties. In particular, infants attend to support and impenetrability information that specifies whether adjacent surfaces are likely to be attached or not. The results also indicate that when the featural and physical properties of a display point to opposite interpretations, infants select the physical over the configural interpretation.

These findings suggest several interesting questions for future investigations. One such question is whether infants younger than 8 months of age are also able to use their physical knowledge to segregate displays. In designing experiments to address this issue, special care will be needed to ensure that the experiments call for physical knowledge that is already available to infants. Consider, in particular, the case of support. Recent evidence has brought to light a clear developmental sequence in young infants' understanding of support (see Baillargeon, 1994, 1995, and Baillargeon et al., 1995, for reviews). This evidence comes from a series of experiments in which infants aged 3 to 6.5 months were presented with support problems involving a box and a platform. The results indicated that, by 3 months of age, infants expect the box to fall if it loses contact with the platform and to remain stable otherwise. At this stage, any contact between the box and the platform is deemed sufficient to ensure the box's stability. At least two developments take place between 3 and 6.5 months of age. First, infants come to realize that the type of contact between the box and the platform must be taken into account when judging the box's stability. Infants initially assume that the box will remain stable if released on the top of the platform, against the side of the platform, or, when a hollow platform is used, under the top of the platform. However, by 4.5 to 5.5 months of age (females precede males by a few weeks in this development), infants are able to distinguish between these different types of contact and recognize that only the first ensures stability. The second development is that infants begin to appreciate that the amount of contact between the box and the platform affects the box's stability. Initially, infants believe that the box will be stable even if only a small portion (e.g., 15%) of its bottom surface rests on the platform. By 6.5 months of age, however, infants expect the box to fall unless a significant portion of its bottom surface lies on the platform.

Given the developmental sequence just described, it should be clear that testing infants aged less than 4.5 to 5.5 months with the cylinder-up display described earlier (Needham & Baillargeon, 1997) would be pointless. Lacking the knowledge that objects are unstable when released against other objects, the infants would have no basis to infer that the cylinder and box must be attached. Infants aged 5.5 months or older, however, could meaningfully be tested with the cylinder-up display. Infants aged 6.5 months and older could also be tested with a version of the display in which the right end of the cylinder rested on the top rather than against the side of the box; recall that by 6.5 months infants realize that the amount of contact between an object and its support affects the object's stability.

Such experiments would be very useful, for at least three reasons. First, the experiments would help determine whether infants less than 8 months of age can bring to bear their physical knowledge when segregating displays. Second, the experiments would help establish whether infants make use of their physical knowledge (a) as soon as it is acquired or (b) only after some time (required perhaps for consolidation or generalization). Finally, it would be interesting to find out how young infants construe support displays involving the cylinder and box in light of their inability to parse these two objects on configural grounds alone. Recall that both 4.5- and 6.5-month-olds failed to parse the original cylinder-down display; only infants aged 7.5 months and older succeeded in segregating the display (Needham, in press; Needham & Baillargeon, in press-a; see section IIIC). Positive data obtained at 5.5 or 6.5 months with support displays involving the original cylinder and box would suggest that, like experiential knowledge (see Section IVA), physical knowledge can help infants arrive at an unambiguous interpretation of a display that is so complex as to overwhelm their capacity for featural analysis.

VI. CONCLUDING REMARKS

We have presented evidence that young infants' organization of stationary adjacent and partly occluded displays is affected by their configural, experiential, and physical knowledge. Such findings indicate that, from a very young age, infants' perception of objects and their boundaries is a complex process that depends on the integration of multiple types of information. This characterization of the young perceiver as one who readily makes use of all the knowledge that she acquires about objects—what objects typically look like, what particular objects or categories of objects exist in the world, how objects generally move and interact—runs counter to more traditional accounts of young infants as limited or modular processors whose perceptual organization is dominated almost entirely by innate principles (e.g., Kellman & Shipley, 1991; Spelke, 1991; Wertheimer, 1958).

A full account of the role of object knowledge in young infants' object segregation will require the weaving together of three distinct research efforts. First, we need to understand the separate developments of infants' configural, experiential, and physical knowledge—how these and perhaps other types of knowledge are acquired, represented, and used at different ages. Second, we need to gain a fuller grasp of the various factors that limit infants' ability to use their object knowledge. For example, recall that young infants can interpret featural information only if they first succeed in representing it (see Section III). Finally, we need to investigate the processes by which infants learn to integrate and resolve conflicts between their different types of object knowledge. We saw in the last section that when faced with conflicting interpretations of a display, one suggested by their knowledge of support or impenetrability, and the other by their configural knowledge, 8-month-old infants opt in favor of the physical interpretation (Needham & Baillargeon, 1997). How is this outcome accomplished? Do infants learn in the course of observing and manipulating objects that support or impenetrability constraints are a much better predictor of a display's organization than are the display's featural properties?

Seeking the answers to these various questions will not only make it possible to begin elaborating an account of object segregation in infancy; it will also reinforce the recent discovery of many fundamental continuities between infants' and adults' minds (e.g., Baillargeon, 1995; Spelke, 1994). Traditionally, researchers were often interested in early perception because they thought of infants as extremely simple "preparations" in which one could study, without the complicating effects of knowledge, experience, or memory, the nature of pure perceptual processes. As the evidence reported in this chapter makes clear, however, such a view must now become an illusion of the past; even young infants are strongly biased to take advantage of all of the knowledge that they possess about objects as they attempt to make sense of their visual world.

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