

6 The Development of Object Segregation During the First Year of Life

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The processes of perceptual organization involve the observer imposing order on stimuli that have many possible interpretations, only one of which is veridical. This order is presumably based to some extent on the stimulus itself but also on the observer's knowledge about the world. As many perceptual theorists have acknowledged, visual perception is a process of interpreting the available visual information, with both correct and incorrect interpretations possible. One question that has intrigued scientists and philosophers for hundreds of years is whether (and if so, to what extent) human infants share adults' ability to organize the visual world. Do infants impose order on visual stimuli in much the same way as adults do? Or do they experience visual arrays as confused collections of shapes, colors, and patterns? These questions, especially as they concern infants' perception of objects, are what motivate this research.

SEGREGATING OBJECTS

How do we tell where one object ends and another begins? The study of object segregation seeks answers to this question. When considering adult perceptions, researchers disagree about the extent to which what we know about objects

affects how we perceive objects (see Palmer, 1999; this volume, for interesting discussions of this issue). Some researchers believe that perception is not influenced by knowledge, either because everything necessary for veridical perception of the objects in the world is contained in the light reflected from those objects (e.g., Gibson, 1979) or because information processing is assumed to take place in individual, cognitively impenetrable modules (e.g., Fodor, 1983). Other researchers argue that the information contained in the visual image is not sufficient to ensure accurate perception and must be augmented with stored knowledge about objects and events (e.g., Biederman, 1987; Kimchi & Haddad, 2002; Peterson, 1994, this volume; Rock, 1983; Shepard, 1983). According to this view, there are many top-down influences from higher to lower levels of visual processing so that knowledge influences even early stages of visual processing. Through our research, we hope to learn more about cognitive and perceptual development by studying the cognitive factors that affect object perception in infancy.

OBJECT SEGREGATION IN INFANCY

Although adults' perception of objects has been studied for some time and has led to many important discoveries about the processes underlying this ability, infants' object perception has been studied for only the past 20 years or so. Kellman and Spelke (1983) were the first to systematically study how infants segregate objects. These investigators asked what sources of information would lead 4-month-old infants to visually unite the visible portions of a partly occluded object. Would infants use the common motion of the object surfaces or the features of the objects' surfaces (i.e., their shapes, colors, alignment)? They concluded that infants used the common motion, but not the common features, of the visible object surfaces to perceive these surfaces as connected behind the occluder. These findings, along with those of other studies of object segregation (e.g., Kestenbaum, Termine, & Spelke, 1987), led researchers to believe that for most of the 1st year of life, infants could use only object motion and spatial gaps between objects as cues for object boundaries.

However, more recent research (see Johnson, 1997, and Needham, 1997, for reviews) suggested that this characterization of infants' visual world is too bleak. Specifically, this research showed that infants use a variety of sources of information to segregate displays, including object features. In this paper, we describe studies that investigate infants' use of different sources of information and discuss the factors that affect infants' use of these sources of information when segregating objects.

METHOD USED IN THE PRESENT RESEARCH

In the experiments reported in this chapter, infants participated in a procedure consisting of a familiarization phase and a test phase. During the familiarization phase, the infants were given the opportunity to observe a stationary display composed of real, three-dimensional objects and to form an interpretation of its composition. During the test phase (except where noted), 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, a portion of the display remained stationary (move-apart event); for the other infants, the two parts moved as a whole (move-together event). If the infants perceived the stationary display as a single unit (an object), their expectation would be violated if the object broke into pieces when pulled. In contrast, if the infants viewed the stationary display as composed of more than one unit, their expectation would be violated if the pieces moved together when one was pulled.

We thus assume that infants form an interpretation of the (stationary) display and that their reaction to the test event, as reflected by the length of their looking, depends on their interpretation of the display. It has been well established that infants tend to direct more attention toward novel or surprising events than toward familiar or expected events (see Bornstein, 1985, and Spelke, 1985, for a discussion of experimental methodologies based on this phenomenon). We use this aspect of infants' looking behavior to help us determine whether infants expect a display to be composed of a single object or of two separate objects.

One important facet of the work reported in this paper is that we reveal to each infant only one possible composition of the display (i.e., we use a between-subjects design) so that no cross-trial contamination of infants' surprise reactions would occur. For example, if infants perceived a particular display as composed of a single unit, they would presumably respond with relatively lengthy looking on the first test trial if the display were shown to consist of two separate units. However, if the second test trial revealed that the display was composed of a single unit, this event could be seen as surprising not because it contradicted their initial expectations about the display but because it contradicted the composition just revealed in the first test trial. Because these surprise reactions over trials could mask infants' true responses to the displays, we reveal to each infant only one of the two possible compositions of the display.

Control studies are not described here (and were not always necessary, depending on the design of the study and the nature of the test events), but they typically involve showing a separate group of infants the test events without a preceding familiarization trial. Because infants tend to watch the test events about equally in these experiments, their results suggest that infants do not have superficial preferences for one event over the other, and they need some familiarization time to examine the display and formulate an interpretation of the display as composed of one or two units.

INFANTS' USE OF PHYSICAL AND FEATURAL INFORMATION

Prior research on physical reasoning in infants (see Baillargeon, 1994, and Spelke, Breinlinger, Macomber, & Jacobson, 1992, for reviews) showed that infants as young as 4.5 months of age share many of adults' most basic beliefs about the behavior of objects. Thus, infants expect objects to continue to exist when hidden; collide with, rather than pass through, other objects; and fall when their supports are removed. With this in mind, Needham and Baillargeon (1997) explored the possibility that infants would use this physical knowledge when determining the locations of object boundaries. For example, because the handle of a drawer seems to rely on the drawer for its support, would infants consider the drawer and handle to be a single unit? Needham and Baillargeon also asked whether infants would use the featural information present in the display (i.e., the shapes, colors, and patterns of the object surfaces) if the physical information of support were not informative regarding the composition of the display. So, to continue our example, if the handle was no longer supported by the drawer, because both drawer and handle lay on the floor, would infants segregate these objects in the same way as before? Finally, the researchers were curious about how infants would integrate information from these two sources when they led to different interpretations of the display (i.e., when physical information contradicted featural information, or vice versa).

In one study, 8-month-old infants' use of information about the solidity of objects was examined (Needham & Baillargeon, 1997). In this study, infants were shown a display with highly similar parts: two adjacent octagons (see Fig. 6.1). At the beginning of each test event, half of the infants were given information about the connection between the octagons: a thin metallic blade encased in a bright red wooden frame was placed beside the octagons for one group of infants (Fig. 6.1A) and between the octagons for another group (Fig. 6.1B). Next, a gloved hand took hold of the right octagon and pulled it a short distance to the side. Half of the infants saw both octagons move as a single unit (move-together event) and half saw the left octagon remain stationary as the right one was pulled (move-apart event). If the infants used the featural information to segregate the display, the infants who saw the blade pass beside the octagons would have seen the octagons as connected and looked longer at the move-apart than at the move-together event. If the infants used the physical information to segregate the display (and if they selected this interpretation in the face of conflicting featural information) the infants who saw the blade pass between the octagons would have seen the octagons as separate objects and looked longer at the move-together than at the move-apart event.

The results showed that the infants who saw the blade pass beside the octagons looked reliably longer at the move-apart than at the move-together event, suggesting that they perceived the octagons as comprising a single object. In contrast, the infants who saw the blade pass between the octagons looked

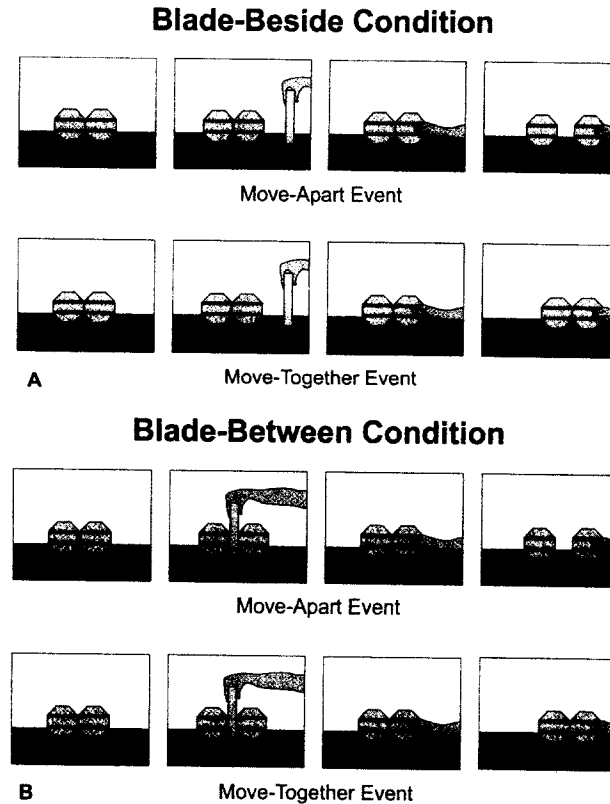


FIG. 6.1. Test events involving octagons whose features indicate they compose a single unit. This information was all the infants in the blade-beside condition (Fig. 6.1A) presumably had to interpret the display. The infants in the blade-between condition (Fig. 6.1B) were also given information about the lack of a solid connection between the octagons as the blade passed through the two octagons. Reprinted from *Cognition*, 62, Needham, A. & Baillargeon, R. Object Segregation in 8-month-old infants, pp. 121-149. Copyright 1997, with permission from Elsevier Science.

reliably longer at the move-together than at the move-apart event, suggesting that they perceived the octagons as two separate units. These results suggest that the infants used both the featural and the physical information in the display to segregate the adjacent objects; when there was a conflict between the interpretations suggested by the two sources of information, infants chose the interpretation based on physical information over that based on featural information.

In a related study, Needham & Baillargeon (1997) examined 8-month-old infants' use of information about the support relations between two adjacent objects to segregate the display. The infants were shown two adjacent objects, a box and a cylinder, with markedly different featural properties (see Fig. 6.2). Half of the infants saw the cylinder resting on the apparatus floor (cylinder down), and half saw the cylinder suspended above the floor, with the box as its only visible means of support (cylinder up). If the infants used the features of the objects to segregate the display, they would see the cylinder-down display as composed of two separate units. However, if the infants used the physical information to segregate the display, they would see the cylinder-up display as composed of a single unit because the cylinder must have support and it must receive its support from the box. Once again, half of the infants saw the move-together event and half saw the move-apart event.

The results showed that the infants who saw the cylinder-down display looked reliably longer at the move-together than at the move-apart event, suggesting that they perceived the cylinder and box as separate objects. In contrast, the infants who saw the cylinder-up display looked reliably longer at the move-apart than at the move-together event, suggesting that they perceived the display as composed of a single unit. These results suggest that, by 8 months of age, infants can use the featural and physical information present in displays of adjacent objects to group their surfaces into separate units. Furthermore, when a conflict exists between the interpretations suggested by featural and physical information, infants choose the interpretation consistent with the physical information. These results also suggest that, like adults, infants may consider physical information to be a more accurate source of information about object boundaries than featural information.

Considered together, the results from these two experiments provide strong evidence that, by 8 months of age, infants can use both featural and physical information to form an interpretation of a display as consisting of one or two objects. When featural information is the only information available to form a clear interpretation of the display's composition, infants use this information to interpret the display. When both types of information are available, infants use physical information preferentially to interpret the displays, even if the featural information suggests a different interpretation. Like adults, infants may consider physical cues a more accurate source of information about object boundaries than featural cues, allowing the former to override the latter when determining the display's composition.

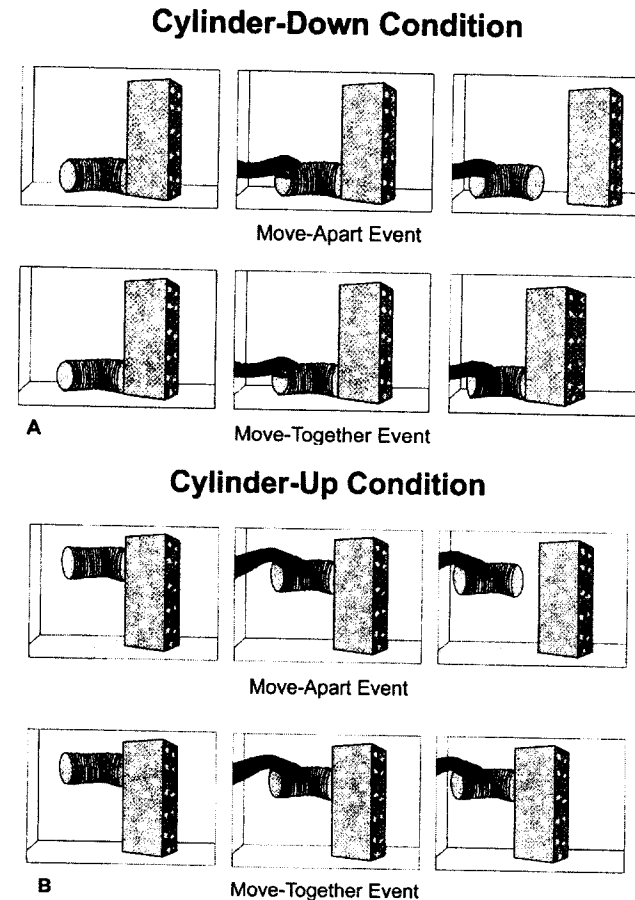
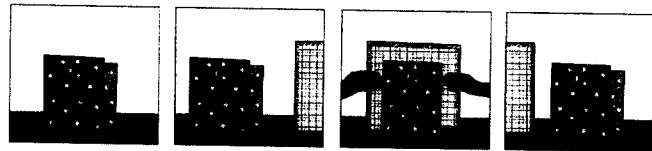
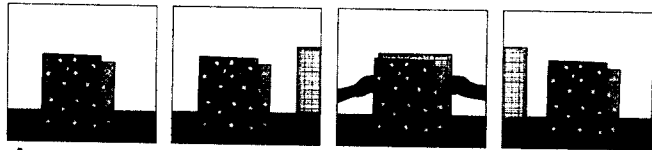


FIG. 6.2. Test events involving objects whose features indicate they compose separate units. This information was all the infants in the cylinder-down condition (Fig. 6.2A) presumably had to interpret the display. The infants in the cylinder-up condition (Fig. 6.2B) were also given information about the presence of a connection between the cylinder and box as the box seemed to provide the cylinder's only means of support. Reprinted from *Cognition*, 62, Needham, A. & Baillargeon, R. Object Segregation in 8-month-old infants, pp. 121-149. Copyright 1997, with permission from Elsevier Science.

Similar - Parallel Condition



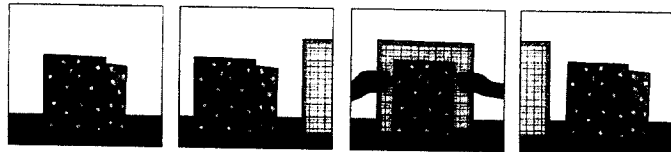
Screen-Between Event



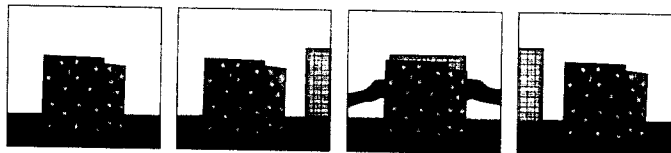
Screen-Behind Event

A

Similar - Angled Condition



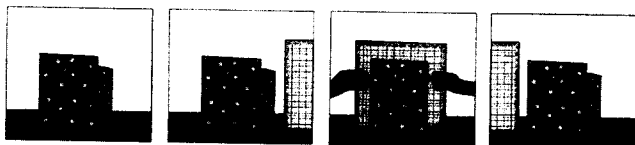
Screen-Between Event



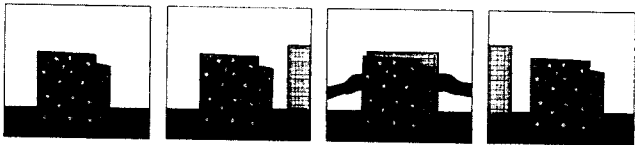
Screen-Behind Event

B

Dissimilar - Angled Condition



Screen-Between Event



Screen-Behind Event

C

INFANTS' USE OF SPATIAL AND FEATURAL INFORMATION

Additional evidence to support this claim comes from a study on infants' use of spatial information (derived from the spatial layout of the objects in the display) and featural information to segregate a display. We investigated the interaction of infants' use of spatial and featural information in a set of experiments in which 9.5-month-old infants were shown one of three displays (see Fig. 6.3). In the similar-parallel display, two identical boxes, one partially in front of the other, were positioned with their front surfaces parallel to each other (and perpendicular to the infants' line of sight). There were two angled displays, in which the back box was angled toward the front box in such a way that it was not clear whether the boxes intersected. One of the angled displays consisted of two identical boxes (similar-angled display) and the other consisted of two boxes with highly discrepant colors and patterns (dissimilar-angled display).

In the test events, the objects were stationary, while a large screen moved either between or behind the objects. If the infants posited a connection between the boxes, they would look longer when the screen passed between the boxes than when it passed behind them. The results showed that the infants who saw the similar-angled display looked reliably longer when the screen passed between the boxes than when it passed behind them, indicating that the infants saw the boxes as connected and were surprised to see the screen pass through the connection. In contrast, the infants who saw the similar-parallel display and those who saw the dissimilar-angled display looked about equally whether the screen passed between or behind the boxes, indicating that the infants who saw these displays expected no connection between the boxes.

These results suggest two conclusions about infants' use of different sources of information in object segregation. First, because the infants saw the similar-parallel display as composed of two separate units, despite the similarity in the featural properties of the boxes, it seems that infants use spatial information instead of featural information to segregate the display. Second, when spatial information

FIG. 6.3. (facing page) Test events involving objects whose spatial arrangements indicate no connection between them (the parallel display shown in Fig. 6.3A) or are ambiguous as to whether there is a connection (the angled displays shown in Fig. 6.3, parts B and C). The objects in the similar-angled display (shown in Fig. 6.3B) had features indicating they were connected; the objects in the dissimilar-angled display (shown in Fig. 6.3C) had features indicating they were separate. Reprinted from *Early Development and Parenting*, 6, Needham, A. & Kaufman, J., Infants' integration of information from different sources in object segregation, pp. 137-147. Copyright 1997, with permission from John Wiley and Sons.

did not lead to a clear interpretation of the display, as in the similar-angled and dissimilar-angled displays, the infants did use the featural information to accomplish this task. Specifically, different featural information (similar or dissimilar boxes) led infants to different interpretations of the displays (as composed of one or two units, respectively). As with physical information, when clear spatial information was available, the infants used this information preferentially to segregate the display. When the spatial information was ambiguous, the infants resorted to using the featural information to accomplish this task.

Together, the results of these three experiments support the claim that, by 8 to 9.5 months of age, infants have a hierarchy of kinds of information used to segregate displays. When multiple sources of information are available, infants tend to use the information that will provide the most accurate interpretation of the display (i.e., either physical or spatial information). However, when a source of information with high ecological validity is not available, infants will form interpretations based only on the available information (in these experiments, featural information).

DEVELOPMENT OF THE USE OF FEATURAL INFORMATION

The experiments described in the previous sections indicate that, by 8 months of age, infants use featural information to group object surfaces into units. But at what point in development does this ability arise? A recently proposed model suggests that the use of featural information to segregate displays depends on a few accomplishments (Needham et al., 1997). First, the infants must be able to detect the features in the display, so basic visual capacities such as acuity and color perception must be sufficiently developed. Second, the infants must have the knowledge that would allow them to interpret the featural information. That is, the infants must have featural knowledge, or the knowledge that abrupt changes in surfaces' featural properties are indications of an object boundary, and that similarity in surfaces' featural properties is an indicator that the surfaces belong to the same unit. And last, infants must be able to process (encode, compare, represent) the featural information present in a display. Lacking any of these three abilities (i.e., a failure in the detection or the processing of the featural information or a lack of featural knowledge) would lead to an indeterminate perception of a display. Conversely, a failure to use featural information to segregate a display could be the result of a failure in any of these three processes.

Because prior research led to conflicting estimates of the age at which infants begin to use object features to segregate displays (e.g., Craton, 1996; Spelke, Breinlinger, Jacobson, & Phillips, 1993), one possibility was that success in segregation tasks could depend on the specific features of the objects in the displays used in these studies. To investigate this possibility, Needham (1998) explored the development of infants' segregation of more and less complex displays.

In this series of studies, Needham (1998) used the cylinder-and-box display that had been used in a prior study of 8-month-old infants' object segregation (see Fig. 6.2A). This set of studies examined 4.5-, 6.5-, and 7.5-month-old infants' segregation of the display by presenting them with the same events as the 8-month-olds saw in the previous study (Needham, 1998; Needham & Baillargeon, 1998). The results showed that the 4.5- and the 6.5-month-old infants looked about equally at the move-apart and move-together events, suggesting that the prominent differences in the objects' shapes, colors, and patterns did not clearly indicate to the infants that the cylinder and box were separate objects. In contrast, the 7.5-month-old infants, like the 8-month-old infants in the previous study, looked reliably longer at the move-together than at the move-apart event, indicating that they saw the display as composed of two separate units.

These results could lead one to conclude that infants develop the ability to use featural information to segregate objects between 6.5 and 7.5 months of age, a finding that is in agreement with some prior research using partly occluded objects (Craton, 1996). However, when the features of the cylinder and box were simplified somewhat (the cylinder was straightened and the box was turned so that a side, rather than a corner, faced the infants; see Fig. 6.4), both the 4.5- and 6.5-month-old infants looked reliably longer at the move-together than at the move-apart event,

Simplified Cylinder-and-Box Condition

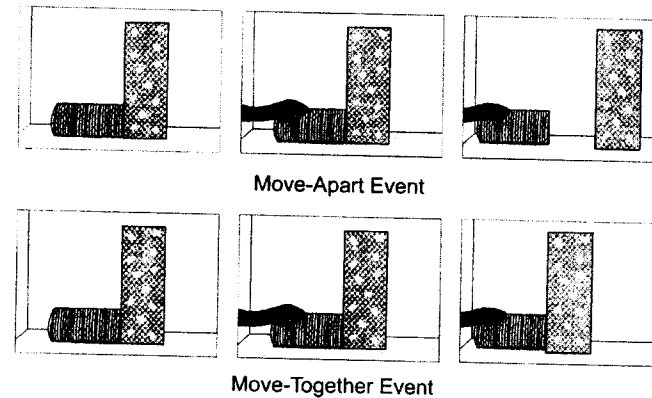
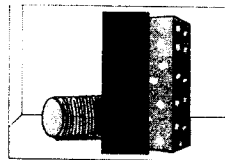


FIG. 6.4. Test events featuring the simplified version of the cylinder-and-box display, in which a straightened cylinder was paired with the test box, which was oriented such that one of its sides faced the infant. Reprinted from *Infant Behavior and Development*, 21, Needham, A., *Infants' use of featural information in the segregation of stationary objects*, pp. 47-76. Copyright 1998, with permission from Elsevier Science.

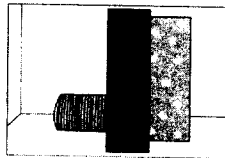
indicating that they perceived the simplified display as consisting of two separate units. These and control results indicated that infants as young as 4.5 months of age have the knowledge that different-looking surfaces typically belong to different objects, but they are only able to use this knowledge to form clear interpretations of displays when the features of the objects in the display are simple to process.

We believe that the best interpretation of these findings is that when the features in a display are too difficult for infants to process, infants are unable to go further in the segregation process and instead produce an ambiguous interpretation for the display. The finding that young infants can use object features to segregate displays has been extended to partly occluded displays as well. In this work, Needham (1998) determined that infants perceive partly occluded versions of the cylinder and box display (see Fig. 6.5) just as they perceive the fully visible cylinder and box. If infants' perception of fully visible and boundary occluded versions of these displays is identical, then infants' interpretations of these displays cannot depend critically on the appearance of the boundary itself. Also, another set of studies indicates that infants perceive partly occluded displays with visible portions that are either highly similar or highly dissimilar in accordance with their featural properties (see Fig. 6.6; see Needham, Baillargeon, & Kaufman, 1997).

Occluded Cylinder-and-Box Displays



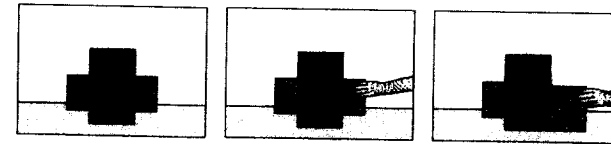
Curved



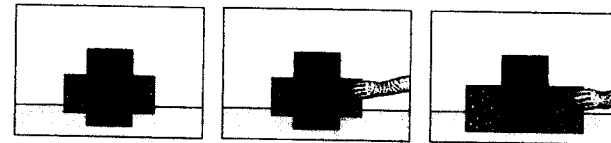
Simplified

FIG. 6.5. Boundary-occluded versions of the displays involving the curved and straight cylinders. Infants interpreted these displays in the same way they interpreted fully visible versions of the displays, indicating that the boundary information was not critical to their interpretation of the displays.

Identical Condition



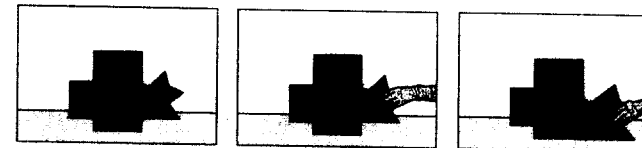
Move-Apart Event



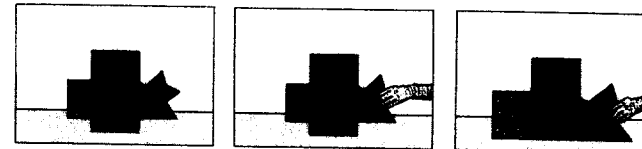
A

Move-Together Event

Nonidentical Condition



Move-Apart Event



B

Move-Together Event

FIG. 6.6. Test events involving partly occluded objects whose visible portions were either identical to each other (identical condition shown in Fig. 6.6A) or were different in shape, color, and pattern (nonidentical condition shown in Fig. 6.6B). Four-month-old infants perceived the identical display as a single object behind the screen; they perceived the nonidentical display as two objects behind the screen. Reprinted from *Advances in Infancy Research*, Vol. 11, Needham, A., Baillargeon, R., & Kaufman, L., Object segregation in infancy, pp. 1-44. Copyright 1997, with permission from Greenwood Publishing Group.

USE OF INDIVIDUAL FEATURES

So far, we have referred to featural information as though it were a single unitary source of information. It is possible that infants use the information in a global or aggregate way as this term suggests, but it also seems possible that certain features of the objects are used and others are ignored. This question of which features are most useful to infants, and whether that changes with development, is the focus of this section of the chapter.

Our approach to this question was informed by the literature on adult object segmentation, which focused considerable attention on the use of object shape to parse displays (e.g., the minima rule, Hoffman & Richards, 1984). Thus, in the first study, Needham (1999) chose to ask whether 4-month-old infants would use shape or color and pattern to segregate two adjacent objects. In one display (similar display), all of the features that could reasonably be manipulated on a real object were designed to lead to the interpretation of the display as a single unit (see Fig. 6.7). Two conflict displays were also created (dissimilar-shape display and dissimilar-color-and-pattern display), in which shape led to one interpretation of the display and color and pattern led to a different interpretation. The research

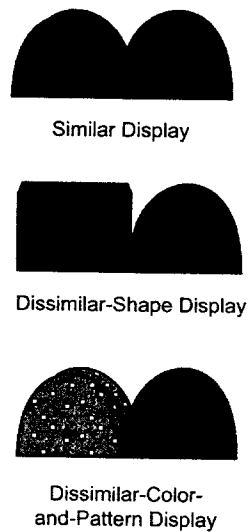


FIG. 6.7. Displays used to investigate infants' use of individual features when segregating objects. The top display involves no conflict between features: Shape, color, and pattern lead to the interpretation of a single unit. In the middle and bottom displays, shape leads to an interpretation different from color and pattern.

goal was that using these conflict displays would help determine whether one of these sources of featural information was relied on more than the other. Such a strategy has proved successful in previous research (Needham & Baillargeon, 1997; Needham & Kaufman, 1997).

As in previous studies, half of the infants seeing each display saw the move-apart event, and half saw the move-together event. Again, the reasoning was that infants' interpretation of the displays would reveal itself by producing longer looking at the unexpected event: Longer looking at the move-apart event would indicate an interpretation of a single unit, whereas longer looking at the move-together event would indicate an interpretation of two separate units. The results showed that the infants who saw the similar display and the dissimilar-color-and-pattern display looked reliably longer at the move-apart than at the move-together test event, indicating that they perceived the display as composed of a single unit. In contrast, the infants who saw the dissimilar-shape display looked reliably longer at the move-together than at the move-apart event, indicating that they perceived the display as composed of two separate units. These results (and those from a control condition) suggest that at 4 months of age, when infants may be just beginning to use features to define object boundaries, object shape may be the feature they attend to most.

To further explore this conclusion, another study was conducted using analogous displays with a more salient color and pattern (Kaufman & Needham, 2003). In this study, 4-month-old infants were shown move-apart or move-together test events featuring one of the displays shown in Fig. 6.8. The top display shows the dissimilar-shape version of the display, and the bottom display shows the similar-shape version. Another goal of this study was to explore infants' use of the boundary seam dividing the two portions of the display as a source of information to segregate the display. Accordingly, versions of both displays were created that did not have a boundary seam. Thus, for each display, the infants' looking times at three events were compared: (1) the move-apart event, (2) the move-together event featuring a display with a boundary seam, and (3) the move-together event featuring a display without a boundary seam. Infants' use of boundary seam, shape, and color and pattern was assessed by comparing the boundary seam and no-boundary seam conditions, as well as the dissimilar-shape and similar-shape displays.

The results were somewhat similar to those described in the previous study, in that it was clear that the infants used shape, rather than color and pattern, to segregate the objects in these displays. So it seems unlikely that the results from the initial study were related to the specific manipulation of color and pattern that was undertaken in that study. Second, the results indicated that the infants did make use of the boundary seam when segregating the dissimilar-shape, but not the similar-shape, display. This result may reflect an interdependence of these two sources of information. Specifically, the boundary seam may be salient when following the outer edge of the objects brings one's eye right to the boundary

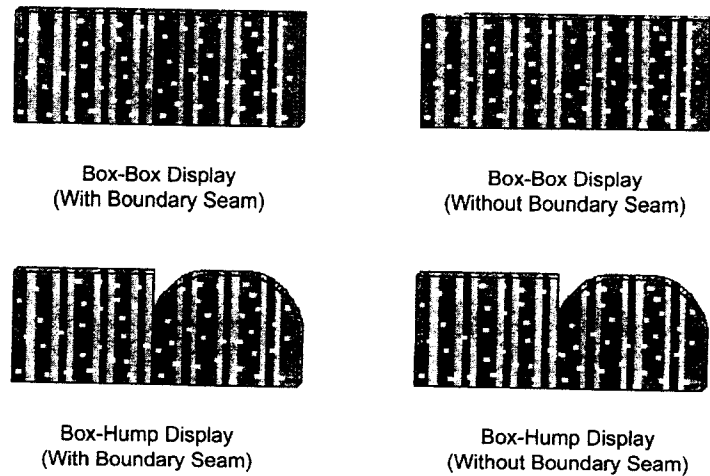


FIG. 6.8. Displays used to examine infants' use of shape, boundary seam, and color and pattern in determining the boundaries between objects. The displays contained parts of the same shape (the displays on the top) or different shape (the displays on the bottom) and either contained a boundary seam between the parts (the displays on the left side) or did not (the displays on the right side).

seam. In contrast, the boundary seam in the similar-shape display may be camouflaged by the series of vertical lines on the surface of the display, so it may not be seen as a seam that could carry information about the composition of the display. Finally, consistent with Needham's (1999) findings, object shape is the source of information infants rely on most when determining the boundaries in a display.

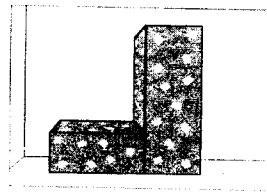
We are currently investigating the development of infants' use of shape and color and pattern later in infancy, and we are focusing on the question of when infants develop the ability to use color and pattern to define object boundaries (Ormsbee & Needham, 2003). Our initial findings regarding this question using the same displays as Needham (1999) are that they have begun to do so by 8 months of age. Infants may even overuse color and pattern at this age, relying on these features even more than shape. This phenomenon is reminiscent of overregularization in language development, in which children temporarily overuse rules for forming past tenses or plurals, extending them to irregular forms (e.g., "goed" or "wented" instead of "went"). Further study involving infants older than 8 months of age will explore infants' use of these sources of featural information toward the end of the 1st year of life.

THE ROLE OF INFANTS' OBJECT EXPLORATION SKILLS

One contributor to the development of infants' object segregation abilities could be improvements in their object exploration abilities. Research by Rochat (1989) indicates that infants go through major advances in their oral, visual, and manual object exploration between 2 and 5 months of age. Specifically, infants at 5 months of age direct significantly more oral and visual exploration toward objects they are holding than they did at 2 months of age, and this exploration becomes more coordinated, with more switching back and forth between the oral and visual modalities. Further, there is evidence for a transition in the modality infants choose for initial exploration of an object between 3 and 4 months of age: At 2 and 3 months, infants choose to explore an object orally first; at 4 and 5 months, infants choose to explore an object visually first. Finally, at around 4 months of age, infants begin to coordinate visual and manual exploration through a more complex behavior Rochat calls *fingering*, in which infants run their fingers over the edges of an object. All of these findings point to important transitions in infants' object exploration skills occurring around 3 to 4 months of age.

To explore possible connections between infants' object exploration and object segregation abilities, the segregation abilities of infants younger than 4 months of age needed to be examined to determine whether this was in fact a period of transition in this domain as well. Prior research from other labs (Kestenbaum, Termine, & Spelke, 1987) suggested that 3-month-old infants tend not to use object features to define object boundaries, but Needham (2000) wanted to assess these abilities using a display that had been shown to be accurately segregated by 4-month-old infants.

In this study (Needham, 2000), older and younger 3-month-old infants were shown the simplified cylinder and box display and either the move-apart or the move-together test events used in previous research (see Fig. 6.4; Needham, 1998). The results showed that the younger 3-month-olds tended to see the display as a single unit, whereas the older 3-month-olds tended to see the display as composed of two separate units. In a second study, the display was changed to one in which the two parts of the display had very similar features (see Fig. 6.9). The infants' responses to the move-apart and move-together test events involving this display suggested that both older and younger infants perceived the display as consisting of a single unit. Together, the results of these two experiments suggest that in the weeks prior to turning 4 months of age, infants begin to use object features to define object boundaries. With this new ability, infants are able to segregate the cylinder-box display into two separate units, while their perception of the box-box display remains unchanged. This pattern of results is consistent with the notion that prior to using features to define object boundaries, infants



Box-Box Display

FIG. 6.9. Display with two similar parts used to investigate the early development of infants' object segregation.

perceive adjacent surfaces as connected in a single unit. Once object features begin to be used, more accurate feature-based interpretations replace the primitive interpretations that are based only on whether the objects are adjacent or not. This developmental framework is consistent with that formulated by Alan Slater and his colleagues to characterize the development of infants' perception of partly occluded objects (Slater, Morison, Somers, Mattock, Brown, & Taylor, 1990).

The findings from this study suggest that infants' ability to use features to segregate at least some objects from each other develops at or just before 4 months of age. The correspondence in ages between the transition in infants' object exploration and the transition in infants' object segregation led us to further explore the possible connection between these two abilities. Needham (2000) chose to examine this connection by giving the same group of infants an exploration task and a segregation task to see whether there would be a correspondence between their performance in the two tasks.

In this study, infants were first given a series of objects to explore orally, visually, and manually (see Fig. 6.10). Each object was placed in the infant's hands and his or her exploration behavior was videotaped. Next, the infant was given an object segregation task using the simplified cylinder-box display used in previous research (Needham, 1998). As in prior work, each infant was shown either the move-apart or the move-together test event, and their looking time was measured. Because completely different objects were used in the exploration and segregation phases of the study, the goal was to determine whether a given infant was a more or less active explorer of objects in general and then determine whether this corresponded to a particular kind of performance in the segregation task.

Infants' object exploration strategies were characterized as more or less active by measuring the percentage of the time they chose to visually or orally explore an object that was placed in their hands. Infants who spent more than two thirds of their time exploring the objects were classified as more-active explorers, and those who spent less than two thirds of their time exploring were classified as

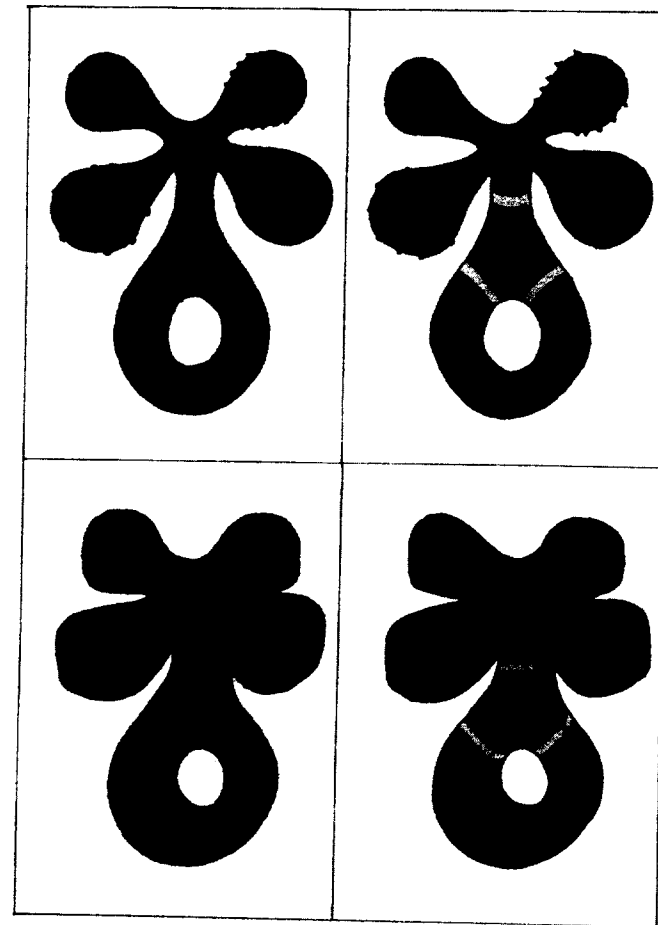


FIG. 6.10. Red teether objects used to assess infants' exploration skills. Infants were classified as high or low explorers, depending on the proportion of time they spent visually or orally exploring the objects. Reprinted from *Journal of Cognition and Development*, 1, Needham, A., Improvements in object exploration skills facilitate the development of object segregation in early infancy, pp. 131-156. Copyright 2000, with permission from Lawrence Erlbaum Associates.

less-active explorers. Looking at the more- and less-active exploring infants' performance in the object segregation task revealed that the more-active explorers looked reliably longer at the move-together than at the move-apart event, indicating that they had successfully segregated the cylinder and box into separate units. In contrast, the less-active exploring infants looked about equally at the two test events, indicating that they were unsure of the composition of the display. These findings indicate a connection between infants' exploration and segregation abilities. The hypothesis we are currently pursuing is that more-actively exploring infants learn more about the objects in their environment and as a result begin to use object features to define object boundaries earlier than less-actively exploring infants.

These findings offer preliminary, but intriguing, evidence that infants' own exploration of objects facilitates their learning about how object features can be used to define object boundaries.

USE OF PRIOR EXPERIENCE IN OBJECT SEGREGATION

One might be concerned that young infants would perceive all displays for which shape did not clearly specify object connections as ambiguous, but our work has shown that this is unlikely to be true. Specifically, infants' prior encounters with objects help them interpret displays that would otherwise be ambiguous. In one series of studies, infants who were not able to segregate the objects in a display during their first encounter with it could segregate the objects if the infants had even a brief prior exposure to one of the objects in the display alone (Needham & Baillargeon, 1998). Further studies have indicated that changes in the features of the objects between infants' first and second encounters with them seem to prevent this facilitative effect, although changes in the spatial orientation of an object do not prevent the effect (Needham, 2001).

We are currently exploring how object knowledge is generalized over collections of objects. Specifically, as infants acquire knowledge about the categories of objects that make up the world, they may use this knowledge to help them interpret displays that would otherwise be ambiguous or that would be incorrectly parsed using object features (Needham, Dueker, & Lockhead, 2003). As in the hierarchy of information use described previously, infants may rely on the general rules about featural information to interpret displays if no additional knowledge can be brought to bear. However, when parsing a display consisting of categories of previously seen objects, infants may bypass these general rules and use category knowledge instead. This process is probably similar to that studied by Goldstone (this volume) in adults.

LIMITATIONS IN INFANTS' OBJECT SEGREGATION: KNOWLEDGE SPECIFICITY

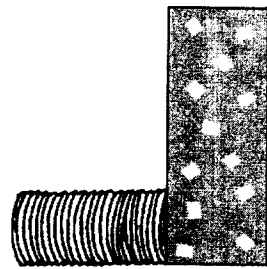
Knowledge specificity has been found in a number of other domains, both within infant cognitive development (e.g., Baillargeon, 1994) and in other areas of infant development (e.g., motor development; see Adolph, 1997). The main idea here is that infants develop knowledge or ability in one narrow area and then fail to generalize to other areas that seem to rely on the same knowledge. For example, Baillargeon proposed that infants acquire separate tracks of knowledge about a variety of different event categories—superficially different kinds of events that may actually rely on the same underlying physical principle. For example, she found that infants are much better at forming expectations about when an object should be visible or not when it is in an occlusion context rather than a containment context (Hespos & Baillargeon, 2001). In seemingly unrelated work, Karen Adolph (1997) found that knowledge infants acquire about traversing potentially dangerous slopes as crawlers does not help them in these same situations once they begin to walk. Rather, infants seem to need to learn all over again which slopes are safe and which are dangerous once they begin walking.

This notion of knowledge specificity discussed by both Baillargeon and Adolph could be relevant for the development of object segregation as well. Specifically, the results of a set of recent studies from our lab suggest that infants develop skills that allow them to segregate objects setting side by side (as all of the studies we have described from our lab have involved), but that these skills may not allow them to segregate objects setting on top of other objects (Needham, 2003).

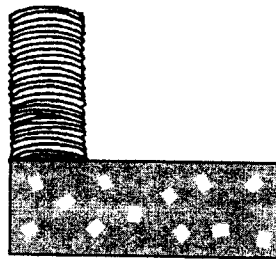
As described previously, when infants around 4 months of age are shown a simple, straight cylinder next to a tall, rectangular box (Fig. 6.11 top), they expect the two objects to be separate. However, when the display is turned on its side so that the cylinder is on top of, rather than next to the box, infants do not parse the display until they are somewhat older—about 12.5 months of age.

In these studies, infants were shown a display composed of the same two objects as in previous research (e.g., Needham 1998, 2000), but, instead of both objects being supported by the floor of the apparatus, the cylinder was supported by the box (see Fig. 6.11 bottom). The infants were shown test events in which a gloved hand grasped the cylinder and raised it into the air: Half of the infants saw the cylinder move apart from the box, which remained stationary throughout the event, and half saw the box move with the cylinder when it was pulled. Infants at four different ages were used in this study: 4.5-month-old infants, 6.5-month-old infants, 8-month-old infants, and 12.5-month-old infants.

The results showed an interesting developmental progression. The 4.5-month-old infants looked reliably longer at the move-apart event than at the move-together event, indicating that they perceived the display as clearly composed of a single



Side-by-Side Display



Stacked Display

FIG. 6.11. Displays used to examine knowledge specificity in object segregation. Both displays were composed of the same cylinder and box. The top display shows them setting side by side; the bottom display shows the cylinder stacked on top of the box.

object. Both the 6.5- and 8-month-old infants looked about equally at the two test events, suggesting that the display was ambiguous for them. Finally, the infants at 12.5 months of age looked reliably longer at the move-together than at the move-apart event, indicating that they interpreted the display to consist of two separate objects, one setting on top of the other.

Thus, when the objects are stacked rather than placed side by side, the age at which infants can clearly interpret the display as two separate objects is 12.5 months rather than 4 months. This set of results suggests that infants may learn how to segregate specific kinds of object scenarios rather than developing and using very general rules for parsing objects regardless of orientation.

One reason for this discrepancy could be that infants probably often see stacked objects moving together, such as when food is carried on a plate, a doll rides in a toy car, or a stack of towels is carried in a laundry basket. Examples of separate side-by-side objects moving together in this way are much harder to imagine.

Infants' own actions on objects may not clarify the situation, either: Depending on whether they grasp the top or the bottom object, stacked objects that are separate may or may not move together. Because common motion is likely to be a very strong cue for object connectedness, infants may initially learn different rules for parsing side-by-side and stacked objects.

MECHANISMS OF DEVELOPMENT IN OBJECT SEGREGATION

What processes contribute to the development of object segregation in infancy? Three kinds of factors may influence the developmental changes described in this chapter: observational factors, basic visual development, and neural factors. First, we think it is likely that infants learn about the presence and absence of connections between adjacent object surfaces from their observations of other people interacting with objects. These observations could occur at some distance (i.e., not performed for or even near the infant), limited only by infants' attention and visual acuity. In addition, we presented evidence to suggest that infants' object exploration skills contribute to their segregation abilities, presumably by giving them more opportunities to learn about the relation between feature changes and object boundaries firsthand. As other researchers have recently noted, self-produced observations may be especially useful in learning (Campos, Anderson, Barbu-Roth, Hubbard, Hertenstein, & Witherington, 2000). In this context, infants' own object explorations may provide them with salient and well-timed information from which to learn about the relation between object features and object boundaries.

Second, the developing visual system also constrains and shapes infants' behaviors. The obvious limitations of the infant's visual system, as exemplified by relatively poor visual acuity and oculomotor control, have been well documented and will not be repeated here. It is worth noting, however, that particular visual development trajectories may underlie the hierarchy of useful object information detailed previously. For example, infants' early tendency to use object shape rather than color may be explained by the lag in infants' color perception abilities compared with overall visual acuity. Infants' ability to see color is not fully mature until 4 months of age (Teller & Bornstein, 1987). Moreover, infants' ability to use color information in cognitive tasks such as object individuation seems to lag even further behind, with infants not succeeding until almost 12 months of age (Tremoulet, Leslie, & Hall, 2000; Wilcox, 1999). These findings are also consistent with the idea that infants prefer to use more ecologically valid cues when given the choice: Shape is a fairly reliable indicator of object boundaries, whereas color, with its massive variability, is not. This may also reflect that shape is multimodal information, available visually, orally, and manually; color, on the other hand, is a purely visual phenomenon.

Third, and most speculatively at this point, is the role of the developing neural system. The brain continues to develop and organize well into childhood, and the role of the brain in behavior continues to tantalize researchers. Some speculation, we believe, is warranted and will doubtless be supplanted as more research examines this exciting topic.

In visual perception, two processing pathways have been identified in primate brains: a dorsal or where/action pathway and a ventral or what/sensation pathway (Livingstone & Hubel, 1988; Milner & Goodale, 1995; Ungerleider & Mishkin, 1982). Each pathway is thought to receive different types of information about the visual world, but the integration and rate of development of each remains largely unknown. (For a detailed discussion of what is known, see Johnson et al., 2001.)

It is attractive to suppose that the progression of infants' object segregation abilities, as well as the hierarchy of information used in this task, is reflected by the relative development of these two different pathways. For example, the ventral pathway subserves featural information such as shape and color, whereas the dorsal pathway subserves spatial and motion information. Could infants' prioritizing of spatial/physical information be due to the earlier development of the dorsal pathway, as compared with the ventral pathway? Further, the relation among types of featural information (shape, color, pattern) suggests that components of the ventral pathway develop individually and in progression, rather than as a unit.

This formulation remains somewhat simplistic, but at this early stage in the new field of developmental cognitive neuroscience, simple ideas must be tested to discover more complex truths. It seems clear that the study of these pathways is relevant for object segregation—after all, our tasks require infants to use these very components of visual perception. However, the relationships here are still tentative and await further study.

CONCLUSIONS

There are a number of conclusions we would like to focus on from the research presented previously, which will be discussed in turn.

Combining of Physical and Featural Information in Object Segregation

By 8 months of age, and possibly earlier, infants use both featural (e.g., shape, color, pattern) and physical (e.g., support, solidity, spatial arrangement) information to segregate objects. Even though features are available and interpretable by infants at this age, they tend not to use that information if (more reliable) physical information about the relations between objects is also available. Thus, we found

that 8- to 9.5-month-old infants systematically use physical information instead of featural information to interpret displays, when both sources of information are available.

Development of Use of Object Features to Define Object Boundaries

Infants regard object features as indicators for object boundaries as early as 4 months of age for simple displays. We have some evidence that this early ability may develop at least in part because of improvements in infants' object exploration skills. Thus, improvements in infants' exploration of object features may lead to learning about the relations between object features and object boundaries.

Further experiments show that early in development, object shape seems to be the most useful feature for infants as they determine the boundaries between objects. Preliminary data from older infants suggests that color and pattern become more important (and shape less important) later in the 1st year of life as infants learn more about the multiple ways in which object boundaries can be predicted.

Learning and Object Segregation

Our research shows that infants use prior experiences with specific objects and groups of objects to facilitate their segregation of the objects in a display. The results of these studies suggest that (a) infants attend to object features, rather than irrelevant cues such as their spatial orientation, when determining whether they have seen an object before as an individual entity; (b) when infants believe they have seen an object before as an individual entity, they expect it will be an individual entity in its current display as well; and (c) infants acquire knowledge pertaining to categories of objects (e.g., the shape of an individual entity in this category) that they then apply to new members considered to belong to that category.

The role of learning in object segregation is also demonstrated by noting the differences in infants' segregation of objects that set side by side and those that are stacked on top of each other. Our findings suggest that infants know quite a bit about how features can be used to segregate objects that are side by side by 4.5 months of age but that this knowledge is not extended to objects that are stacked on top of each other until the end of the 1st year of life.

Final Thoughts

The findings presented in this paper highlight the many strengths and weaknesses in infants' early object segregation abilities and point to some interesting developmental processes that may underlie these changes. Future research on these and related topics will add much to our understanding of the development of perceptual

organization during the 1st year of life and how developments in brain and behavior influence these changes.

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7 Learning to Perceive While Perceiving to Learn

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The world we experience is formed by our perceptual processing. However, it is not viciously circular to argue that our perceptual systems are reciprocally formed by our experiences. In fact, it is because our experiences are necessarily based on our perceptual systems that these perceptual systems must be shaped so that our experiences are appropriate and useful for dealing with our world.

The notion that our perceptions are experience driven has been construed as everything from mundane to magical. At the mundane (at least, well-understood) pole, much is known of the mechanisms underlying simple sensitization and habituation. Through sensitization, repetitive presentation of a stimulus leads to increased sensory response to the stimulus. Through habituation, repetitive presentation of a stimulus leads to decreased responsiveness. The neurochemical circuitry underlying the sensitization of the *aplysia*'s gill withdrawal response is well understood (Frank & Greenberg, 1994). Closer to the magical end of the continuum, scholars have argued for profound perceptual consequences of experience. Kuhn (1962) described how scientists, when exposed to a particular theoretical paradigm, see physical phenomena in new ways: "Though the world does not change with a change of paradigm, the scientist afterward works in a different world" (p. 121), and "during [scientific] revolutions, scientists see new and different things when looking with familiar instruments in places they have looked before" (p. 111).