


INFANTS’ USE OF PRIOR EXPERIENCES WITH OBJECTS IN OBJECT SEGREGATION: IMPLICATIONS FOR OBJECT RECOGNITION IN INFANCY

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On one of their first trips to the library, a mother holds her baby boy and points out some of the interesting sights around them. As the baby looks at the rows and rows of bookcases, one can only speculate about what impressions he has of the books on the shelves. Most likely, a young infant (at three months or younger) studying a row of spines belonging to tightly packed books on a shelf would not interpret this display as a collection of individual objects. However, how would his impression of the display change after seeing someone walk up to the shelf he was studying and remove a book? Would he now (or soon, after several such experiences) have the impression of the books as a collection of items on the shelf? And would this experience transfer to other shelves of books in the library? In this chapter, we explore this question of how prior experiences with objects influence infants’ perception of displays containing these previously seen objects and objects similar to them.

I. Object Segregation

One of the most important problems in vision is how we determine which surfaces belong together as a single object and which belong to separate objects. Accurate segmentation of a scene is likely to be related to our identification of objects. Perhaps we typically segment a display into its units prior to identifying the object(s) present, but one of the main themes of this chapter is that this process can take place in reverse as well—that sometimes we segment displays into their appropriate objects because we recognize or identify the objects in the display. A similar point has been made in the adult literature by Mary Peterson (1994), who has shown that even though we might typically think of figure-ground segregation as something that takes place prior to object recognition, adults sometimes recognize a figure in a display prior to (or while) establishing the figure-ground organization of the display.

Evidence for infants’ use of this kind of process would lead to new kinds of research questions being asked. We would want to know when and how infants begin to learn about the types of objects that exist in the world, perhaps first on the basis of features such as shape (round objects, cylindrical objects) or even animacy (animate objects, inanimate objects). The first year of life would be seen as a time for infants to build this catalog of object types, which may over time develop a hierarchical structure (cylindrical objects: those that hold substances (e.g., beverage cans, cups), and those that do not (e.g., hot dogs, candles). This framework of knowledge about the objects in the world may be perceptual in origin, but may serve as a foundation to which more conceptual information is added (Elman, 1994). These ideas for the future of research in this area serve to highlight the potential importance of this process.

A. PHYSICAL AND FEATURAL INFORMATION IN OBJECT SEGREGATION

Most of the research on infants’ segregation of displays into objects has been focused on their ability to use certain kinds of visually available information either (a) to group together the visible portions of a partly occluded object or (b) to find a boundary between two spatially contiguous objects. To accomplish either of these tasks, infants must (as Slater et al., 1990, have claimed) engage in “perceptual inference,” going beyond what is directly given in the display. Infants must do more than simply perceive the information present in the display; they must also be able to determine what the information suggests about the composition of the display. They must apply rules they have abstracted about the properties of objects to the information present in a display.

Two kinds of information have been somewhat extensively studied: physical information and featural information. Physical information typically refers to facets of objects’ interactions with each other, such as their relative or common motions, spatial relations, and support relations. If one has the requisite physical knowledge (e.g., that inanimate objects cannot act on each other at a distance, that the surfaces of a single object cannot be separated by spatial gaps, that all objects require support), then physical information in a display can be used to segment it. Featural information refers to the shapes, colors, patterns, and textures of objects. If one has the knowledge that objects tend to be regular in their featural properties, then abrupt changes in one or more of these features may be perceived as an indication of a boundary between two objects. The existing literature suggests that to find object boundaries, infants use at least certain kinds of physical information by 2 months of age, and at least certain kinds of featural information by about 4 months of age, and by 6 months of age (if not earlier) infants resolve conflicts in interpretations suggested by these two sources of information by favoring the interpretation suggested by physical information (e.g., S. P. Johnson & Aslin, 1995; Needham, 1997; Needham & Baillargeon, 197; Needham & Kaufman, 1997; see S. P. Johnson, 1997; Needham, Baillargeon, & Kaufman, 1997; and Spelke, 1990, for reviews).

B. PRIOR EXPERIENCE IN OBJECT SEGREGATION

In this chapter, we explore yet another source of information infants may use when segregating displays: prior experiences with objects. As Needham et al. (1987) first suggested, infants may use their prior experiences to form a clear interpretation of a display even when they cannot form a clear interpretation based on other sources of information in the display. Infants could use their prior experiences with objects in at least two ways in interpreting a display. First, they may
recognize a specific instance of an object they have seen before, and on this basis alone be able to find its boundaries. For example, the first time an infant daughter sees her mother’s key ring, she may encode extensive information about its shape, colors, and materials. The second time she sees the key ring, when it is on the living room table next to the remote control for the television, she may know that it is separate from the remote control, even if she has never seen the remote control before.

The second way infants may use their prior experience is by categorizing a previously unseen object as a member of a category about which they possess some knowledge. For example, after an infant has had experience with her mother’s key ring, a key ring rattle, and perhaps even several other instances of key rings observed in the grocery store parking lot, she may not have difficulty determining that a key ring she sees on a neighboring table at a restaurant is separate from an adjacent fork (and predicting exactly where the boundary between the two objects is). By this time, the infant may even have certain expectations about what key rings seem to do (i.e., that they are associated with entry into houses and cars), and what their presence often signals (i.e., an imminent departure).

II. Feature Integration Theory

Adults’ recognition and identification of objects has been extensively studied, using a variety of stimuli such as letters, words, and line drawings. Overall, many researchers would agree that the process of object or pattern recognition is at least a three-stage process (Kahneman, Treisman, & Jacobson, 1992). First, the basic features of the display are extracted. Next, a representation of the display is created that includes featural information (e.g., shape, color, pattern) from the display. Finally, this representation is compared to representations stored in memory and the object(s) in the display is (are) identified.

The general sequence of processes sketched out above could be further explained in many ways, but one highly influential theory of how we recognize objects is Feature Integration Theory (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992; Kahnstein, 1991; Loeve, 1997). This name comes from a basic assumption of the theory: that the individual features of an object are first registered as independent entities and are later integrated into a unified representation of an object. According to this theory, an object file is formed very early in the process of perceiving an object, and this file is used to collect information about the object, such as its color or shape. Once attention is focused on the information in the object file, an object token, or representation of this specific object, is formed. When an object token is formed, the features of the object are bound together (in a process called “binding”) as part of this token.

Object tokens are thought to be formed for each newly perceived entity, and each object token is compared with the available object types stored in memory. A successful match between token and type completes the identification process. Of course, we sometimes recognize a previously seen object as something we have seen before without being able to identify it, and this theory allows for recognition of particular tokens even if they have not been matched to a known object type. This aspect of the theory lends itself well to perceptual learning, as it would allow infants to recognize an object they know very little about. One important aspect of this theory for the purposes of the present discussion is that our catalog of known “types” could begin as common and/or simple items such as faces, circles, and squares, and could grow into the rich and complex array of objects known to an adult.

III. Feature Integration Theory in Infancy

Can Feature Integration Theory be used to explain how infants recognize objects? Some research suggests that infants may have difficulty in binding the features of an object to whatever mental representation is formed of the object (Leslie, Xu, Tremoulet, & Scholl, 1998; Xu & Carey, 1996). For example, the results of a number of studies suggest that, like adults, infants rely more on spatiotemporal information than on featural information when keeping track of the identity of objects (Simons, 1996). These studies demonstrate that under certain circumstances, infants respond as though they are unsure whether a change in features between the disappearance and reappearance of an object necessarily means that two distinct entities are involved in the event.

In these studies, infants do not seem to believe that every new set of features should correspond to a new entity. However, other studies show that when the events are simplified considerably, infants respond with surprise when the number of different entities does not equal the number of different sets of features (Wilcox, in press; Wilcox & Bialargeon, 1998).

In Feature Integration Theory terminology, infants apparently (a) do not always open a new object file for each novel set of features they see, (b) do not always return to an old object file when they should, or (c) have difficulty in binding the features of a new object together to form a particular object token. Although little of the existing research in this area would allow us to discriminate between the first two possibilities, some researchers have investigated the binding issue. In one study, Slater and his colleagues (Slater, Mattock, Brown, Burnham, & Young, 1991) familiarized newborn infants with two stimuli that differed in both color and orientation (e.g., one was a vertical red line and the other was a diagonal green line). The infants were then tested to determine whether they remem-
bered the particular color-orientation compounds they had seen. During testing, infants saw one of the stimuli they had seen during familiarization paired with a stimulus representing a novel relation between color and orientation. If the infants were unable to bind together the particular color-orientation combinations they experienced, they should have looked equally at the familiar and novel combination of color and orientation. However, the results showed that the infants looked reliably longer at the novel combination, indicating that the infants were capable of encoding and remembering the combination of features they experienced in the familiarization phase of the study.

Building on this finding, Bhatt and Rovee-Collier (1994, 1996) have shown (using a different procedure that included lengthy exposure to the familiarization stimulus) that 3-month-old infants can remember feature combinations even after a 24-hour delay. The findings suggest that when given enough time, infants can encode extensive and detailed information about objects and remember this information for 24 hours or more. Such findings suggest that infants are usually able to bind a collection of features together to define a particular object (or object token).

Thus, the Leslie et al. (1998) and Xu and Carey (1996) studies may indicate that when spatiotemporal information identifies just one object in a display, and featural information identifies two distinct sets of features, infants tend to favor the interpretation based on spatiotemporal information over that based on featural information. Other studies also suggest that infants pay less attention to featural information when information about, for example, the motion of objects, the spatial layout of objects, the solidity of objects, or the support relations between objects conflicts with the featural information (Kellman & Spelke, 1983; Needham & Baillargeon, 1997; Needham & Karrman, 1997). In all these cases, research has shown that infants tend to favor the interpretation based on the physical information present in the display rather than the features of the objects. This pattern of findings may reflect the relative ecological validities of the different kinds of information, as physical laws are more inviolable than rules based on featural information (e.g., all objects require support, but not all objects are uniform in shape, color, and pattern). One explanation for this pattern of findings is that infants are sensitive to the ecological validities of the various kinds of information they learn about, and they favor interpretations based on sources of information with higher ecological validity over those based on information with lower ecological validity (Needham, 1997).

Clearly, more evidence is needed before we can determine whether Feature Integration Theory is an appropriate explanation for how infants recognize and identify objects and if so which aspects of infants’ abilities differ from those of adults. In this chapter, we review work from our laboratory addressing the issue of how infants encode and represent a collection of features that defines an object.

IV. Infants’ Recognition and Categorization of Objects

Many controversies remain about the best way to explain how adults recognize and identify objects, for example, whether the representation used during recognition is viewer centered or object centered (Biederman, 1987; Tan; Buhltorf, Zabiniski, & Blalau, 1997). However, much is known about how adults accomplish these tasks and researchers agree on many basic points. In comparison, much less is known about the development of these processes. In many (if not all) areas of psychology, understanding the origins and development of a process or behavior often leads to fundamental changes in our understanding of the phenomenon in its mature form (Baer, 1982; Baron & Galizio, 1983; Berlyne, 1965; Bijou, 1984; Bugelski, 1956; Reese, 1989; Spelke & Van de Waal, 1993; Toulmin, 1971; Watson, 1926). Object recognition in infancy is an important, but relatively neglected area of study.

A. OBJECT RECOGNITION

Beginning with the groundbreaking work of Fantz (1963), a long history of research findings has supported the conclusion that from birth and even before (see DeCasper, Lecanuet, Busnel, Granier-Deferre, & Maugeais, 1994; DeCasper & Spence, 1986; Hepper, 1991), infants encode and remember stimuli from their environment. Many visual recognition memory studies have provided evidence that infants (even newborns, see Slater et al., 1990, 1991) spend less time looking at a stimulus they have seen before than at a novel stimulus. These studies have dealt with variables that influence infants’ recognition, such as the amount of initial study time given and the delay interval between familiarization and test. These studies have indicated that by 5 months of age, infants recognize previously seen stimuli after only modest amounts of familiarization (e.g., Cornell, 1979; Fagan, 1970, 1971, 1974; Lasky, 1980; Martin, 1975; Rose, 1980, 1981). For example, Fagan (1974) examined the length of familiarization 5-month-old infants required to recognize various stimuli on immediate memory tests. He found that although 20 to 30 s of familiarization time was needed for faces, and 17 s for abstract patterns composed of identical elements, as little as 4 s was sufficient for patterns that looked familiar to different from each other.

When infants are given extensive amounts of familiarization time with a particular stimulus, as in Rovee-Collier’s mobile conjugate reinforcement paradigm, research indicates that infants acquire detailed and lasting representations of the stimulus. For example, infants as young as 2 months of age remember details of the stimulus 24 h after training, and as infants get older, their representations of the stimulus remain detailed for longer periods of time. As the interval between
training and testing increases for any particular age, infants notice fewer discrepancies between the training and testing stimuli, suggesting that their representations lose detail over time (Rovee-Collier, 1993; Rovee-Collier & Sullivan, 1980).

Beyond the basic questions of the conditions under which infants remember a previously seen stimulus, researchers have asked whether a prior experience with a specific object affects infants’ subsequent perception of the object. This question was investigated in a study by Granrud, Haake, and Yonas (1985) on infants’ use of familiar size as a cue for depth. Typically, the use of familiar size as a depth cue has been studied using objects that are likely to have sizes that are quite familiar (e.g., a human face). However, Granrud and his colleagues explored whether familiar size would be used when the familiarity was acquired during a brief period of time at the beginning of the study. Specifically, they tested whether prior experience with two objects that differed in size would facilitate 7-month-old infants’ use of familiar size to determine which of the two objects was closer (and potentially reachable) during testing. In their study, infants first participated in a 10-min play session in which two novel experimental objects were featured, one large and one small. In test, equally large versions of both objects were placed in front of the infants, who viewed the display monococularly to eliminate binocular cues.

Granrud et al. reasoned that if the infants’ prior experience with the objects influenced perception of the objects’ relative distances, then the small object in the play session should be perceived as closer than the large object. If so, they should reach more for the previously small object because the infants tend to reach more for objects they perceive as closer. Exactly this result was obtained.

In summary, the evidence from the object recognition literature leads to three main conclusions. First, infants recognize objects they have seen before if the familiarization time is sufficiently long. Second, when familiarization time is long, infants recognize extensive detailed information about object features. Finally, infants’ prior experiences with objects affect their subsequent perception of those objects. These conclusions are important premises for the issues investigated in our own research, described later in the chapter.

From the perspective of Feature Integration Theory, the literature on infant object recognition indicates that infants are able to set up object tokens and that they recognize a previously seen token on subsequent encounters. In the next section we explore evidence about the identification process, in which a particular object token is compared to representations of types that are stored in memory.

### B. OBJECT CATEGORIZATION

Some of the earliest work on categorization in infancy was designed to address the question of whether infants form perceptual categories: Do infants form groupings of objects based on perceptual categories such as shape or color? One of the earliest studies on this question was conducted by Ruff (1978). She showed 6- and 9-month-old infants a series of objects that were the same in three-dimensional shape, but different in size, color, and orientation. After the infants were presented several instances of this shape category, they were given test trials featuring two objects, one a novel instance of the same shape category and the other a novel object of a different shape. The results showed that the 9-month-old infants looked reliably longer at the novel-category object than the familiar-category object, but the 6-month-old infants did not show a reliable looking preference. Thus, under the conditions of these experiments, 6-month-old infants either did not form an internal representation of the shape of the familiarization objects or formed it and did not use it to interpret the shapes of the test objects.

Whether infants younger than 9 months of age can form and use categorical representations was a question of considerable interest. A new method was devised by Bomba and Siqueland (1983) to investigate 3- and 4-month-old infants’ categorization of abstract, two-dimensional patterns created by a collection of black dots on a white background. The researchers first familiarized infants with several different instances of a shape category; each instance was created by perturbing a prototype shape to a different extent. Then in test, the infants were shown a pair of stimuli they had never seen within the context of the experiment: one was the prototype of the familiarized shape category and the other was the prototype of a different shape category. The results showed that the infants looked reliably longer at the novel-category prototype than at the familiar-category prototype, indicating that they had formed and used a shape category during familiarization.

In further experiments, Bomba and Siqueland (1983), Quinn (1987), and Younger and Gottleib (1988) used the same general design to explore additional aspects of the categorization context that influenced infants’ categorization performance, including memory load, the number of categories represented in the exemplars (exemplars from one or two categories), and the complexity of the patterns used as stimuli. The results of both Bomba and Siqueland (1983) and Quinn (1987) suggest that under conditions of high memory load, infants form a central representation for the category and maintain some memory for the characteristics of individual exemplars. In contrast, under conditions of high memory load, infants tend to form a central representation for the category and do not maintain memory of the individual characteristics.

Studies of young infants’ categorization of other kind of stimuli, such as animals, vehicles, colors, spatial relations, faces, and containers, suggest that infants notice what is changing and what is unchanging across a set of exemplar displays and that they use this information to form categories quite readily.

The evidence described above makes clear that even young infants have the ability to categorize objects. Our next question is whether infants’ assignment of an object to a particular category (essentially, their identification of the object as a kind of thing they know something about) influences their perception of these objects. Does knowing what kind of object something is help infants perceive it dif-
criminally different objects and regarding a previously unseen member of the category as familiar. Second, the studies by Bertenthal, Schwartz, and Vishton suggest that infants acquire information about categories they experience on a day-to-day basis. Infants use this information to interpret displays.

In the next section we describe our research on infants’ ability to segregate objects using their prior experiences in the ways outlined above. Before describing these experiments, we briefly describe our research methods.

V. General Method of Current Studies

The method used in most of our experiments was adapted from that devised by Spelke (e.g., Spelke, Breinfinger, Jacobson, & Phillips, 1993). The infants participated in a familiarization phase and then a test phase. During the familiarization phase, the infants saw the stationary test display, a display similar to the test display, and/or a portion of the test display. Many of the experiments reported here involved assessing the effects of slightly different experiences during the familiarization phase. 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 of the display remained stationary (move-apart event); for the other infants, the two parts moved as a whole (move-together event).

Another line of research has dealt with infants’ perception of displays containing representations of human faces. This research indicates that from birth, the human face may hold special interest for infants (M. H. Johnson, Dziurawiec, Ellis, & Morton, 1991). Thus, one may expect that infants are collecting considerable information about human faces and may use this information to help them interpret face-like displays. Schwartz (1982) compared 5-month-old infants’ perception of partly occluded checkerboard displays and partly occluded face displays. She found that the infants did not perceive the visible portions of the checkerboard display as connected behind the occluder, but they did perceive the visible portions of the face display as connected behind the occluder. Vishton, Stulac, and Calhoun (1985) obtained similar results: 6-month-old infants reached for partly occluded faces as though they perceived the displays as connected behind the occluder, but did not reach for partly occluded geometric figures.

C. SUMMARY

The studies reviewed in this section suggest two main conclusions. First, extensive evidence indicates that infants as young as 3 months of age can learn categories based on object form, noticing similarities in the shapes of a group of dis-
vided into 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. Agreement per trial per infant averaged 92% across experiments. The primary (i.e., more experienced) observer's looking times were used to determine the end of the trials.

An experimenter stationed beside the apparatus controlled the familiarization and test events using precise, second-by-second scripts that were practiced until they were performed smoothly and accurately. A metronome beating softly once per second helped the experimenter adhere to the scripts.

The infants received one to three familiarization trials at the start of the experiment. In some cases, familiarization trials were quite brief and ended when the infant had accumulated a preset amount of looking time at the display. In other cases, familiarization trials ended when the infant either (a) looked away from the display for 2 consecutive seconds after having looked for 10 cumulative seconds or (b) looked at the display for a maximum of 30 consecutive seconds. Following the familiarization trial(s), the infants received two to six test trials (experiments with older subjects typically had two trials, and experiments with younger subjects typically had six trials). In each test trial, the test 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 after looking for the minimum amount of time for that experiment (6–8 s, depending upon the length of the event cycle), 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 lifted again to begin a new trial.

A between-subjects design was used in all of the experiments reported in this chapter; each infant saw only the move-apart test event or the move-together test event. Although this design prevents a direct assessment of each infant's perception of the display, it allows us to determine the group percept over the age range tested, assuming that this percept is consistent over the infants in the group. We believe that a between-subjects design may be a more sensitive measure of infants' initial interpretation of the display, because it avoids cross-contamination of infants' responses to the two test events. It also provides a more realistic situation to infants, as each infant is shown that a given display is either composed of one unit or two separate units but not both.

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

VI. Initial Study

Although our goal was to investigate the effects of a brief prior exposure to one portion of a display on infants' perception of the display, we began this research by first determining infants' perception of the composition of a display consisting of two parts with distinctly different features (see Figure 1): a tall, blue box with white squares and a curved yellow cylinder (Needham & Baillargeon, 1998). After a familiarization trial during which the display was seen stationary, the infants were shown a test display in which a gloved hand took hold of the cylinder and moved it a short distance to the side. Half of the infants saw the cylinder move apart from the box, which remained stationary throughout the event (move-apart event), and half saw the box move with the cylinder as a single unit (move-together event). The infants were 4.5, 6.5, 7.5, and 8 months old.

The results showed that for the 4.5- and 6.5-month-old infants, the mean looking time was about the same whether they saw the move-apart or the move-together test event, indicating that the composition of the display was ambiguous to them (Needham, 1998). Two other groups were given no familiarization trial prior to seeing one of the two test events, and they also had about the same mean looking times. In contrast, following the familiarization trial, the 7.5- and 8-month-old infants perceived the display as clearly composed of two separate units. Further studies revealed that even 4.5-month-old infants can use object features to determine object boundary locations, but that they do so only when the features of objects are very simple (Needham, 1998, 1999d).

Test Events

Fig. 1. Schematic drawing of the cylinder and box display and the move-apart and move-together test events shown to the infants in the experiments described in sections VII and VIII. Reprinted from Infants Behavior and Development, Vol. 21, A. Needham & R. Baillargeon, "Effects of prior experience in 4.5-month-old infant's object segregation," p. 4, Copyright © 1998, with permission from Elsevier Science.
VI. Recognition-Based Process

In the present section and the next one, a series of experiments is described in which 4.5-month-old infants were given prior experience with an object either identical or similar to an object to be seen in the test display, and the effects of this experience on infants’ responses to the test events described above were assessed.

A. EFFECTS OF PRIOR EXPERIENCE WITH A TEST OBJECT

1. Effects of Immediate Prior Experience

Our next step was to give 4.5-month-old infants a brief exposure to either the cylinder or the box immediately prior to testing. If the infants were able to make use of this prior experience to help them perceive the display as clearly composed of two separate pieces, they should look reliably longer at the move-together event (which is counter to this interpretation) than at the move-apart event (which is in line with this interpretation). In our first study, we gave infants a 5-s exposure to the tall blue test box alone immediately prior to the test event, which was move-apart for half of the infants and move-together for the other infants. The mean looking time was significantly longer for the move-together than the move-apart test event, indicating that the infants perceived the display as composed of two separate units. These findings suggest that 4.5-month-old infants can make use of their prior experiences with objects to determine the locations of object boundaries in a display containing these objects. However, we sought further evidence to support this conclusion by assessing the effects of a brief prior exposure to the cylinder.

We used the same procedure, except that we showed the cylinder alone rather than the box alone prior to testing. The mean looking times were about the same for both the test events, indicating that the infants did not use the prior experience when segregating the test display. Although several interpretations of this finding are possible, we decided to determine whether infants’ use of prior exposure depends upon having sufficient time to process the object during the initial exposure. Studies have shown that infants need more time to process more complex displays sufficiently for later recognition (e.g., Fagan, 1974), and the cylinder seemed more complex than the box. We therefore decided to increase the length of the initial prior exposure to the cylinder to 15 s. After seeing the cylinder alone for 15 s, the mean looking time was reliably longer for the move-together than the move-apart event, indicating that the infants used the prior experience to segregate the test objects into two separate pieces.

One conclusion that can be drawn from these results is that infants recognize the portion of the test display seen prior to testing. Another conclusion is that recognizing the previously seen object allows infants to segment the test display into two separate units. Infants use their prior experience with a portion of the test display to help them form an interpretation of the display that would be ambiguous to them without the prior experience. These conclusions are important because they indicate that infants interpret the sequence of experiences in much the same way as adults.

2. Effects of Delay and Context Change

Our next step was to determine the effects of delay and context on infants’ use of prior experiences for segregating a display. In two studies designed to assess the effects of delay, a delay of about 24 h (Mean delay = 24 h, 10 min) was introduced between the initial experience with the test object and the presentation of the test events (Needham & Baillargeon, 1998; Needham & Modi, 1999b). The infants were 4-month-olds. An experimenter visited each infant in his or her home and showed the infant either the test box or the test cylinder for approximately 2 min. Fagan (1970, 1971, 1973) had found this familiarization time sufficient for recognition in 5-month-old infants with delays of 1 to 14 days. About 24 h later, the infant was brought to the laboratory for the test phase. Again, half of the infants saw the move-apart event and half saw the move-together event. In both studies, the mean looking time was reliably longer for the move-together than the move-apart event. The infants who had seen the box prior to testing looked reliably longer at the move-together than at the move-apart event only in the second block of tests (trials 3–6), but the infants who saw the cylinder prior to testing looked reliably longer at the move-together than at the move-apart event over all six test trials. The reason for this difference is unclear, although we are exploring the possibility that the cylinder’s complexity and unfamiliarity may make it more distinctive and more memorable than the box. These findings suggest that even when the initial and subsequent views of the object occur about 24 h apart and in different contexts, infants are still able to use the prior experience to segment the test display into two separate units.
3. Effects of Lengthier Delays

In a follow-up study currently under way (Needham & Modi, 1999b), the delay between familiarization and test is 72 hr. So far, the results are not promising, leading us to suspect that some time between 24 and 72 hr after their initial exposure to one of the test objects in their home, infants are no longer able to use the prior exposure to segregate the test display they see in the laboratory. If this finding holds up, infants' failure after a 72-hr delay will not be consistent with the retention functions that Rovee-Collier and her colleagues have found in infants (see Rovee-Collier, 1993, and Rovee-Collier & Hayne, for a review of this work). Specifically, their research shows that even 3-month-old infants remember their prior experience with a mobile for around 9 days after training. However, Rovee-Collier's procedures differ in many ways from ours. Two important differences are the amount of familiarization the infants receive of the relevant object or situation (about 30 min in Rovee-Collier's studies vs. 2 min in ours), and the similarity in context during the initial and subsequent encounters with the test stimulus (training and testing in the home in Rovee-Collier's studies vs. familiarization in the home and testing in the laboratory in our studies). These two factors (and possibly others) could contribute to the longer retention in her studies than in ours.

B. EFFECTS OF PRIOR EXPERIENCE WITH A SIMILAR OBJECT

The findings of the experiments described above did not indicate the processes infants use in segregating a display. Recognition of the previously seen object might be required for infants to benefit from the prior experience when segregating the test display, but the recognition process can be characterized in different ways. One possibility is that infants encode much about the object during their initial brief exposure to it, and that their recognition of the previously seen object requires a close match between the features of the object on the first and second encounters. Alternatively, infants may not encode specific information about the object during the initial brief exposure, but can "recognize" the object without a close match in features. Perhaps prior experience with any object of the same shape or color as the corresponding test object would be sufficient to facilitate infants' segregation of the test display.

In an attempt to answer questions such as these and produce a more complete explanation of the factors influencing infants' use of their prior experiences in perceiving objects, we conducted a series of experiments on the effects of prior experiences with objects similar but not identical to the test objects on infants' segregation of the test display (Needham, in press; Needham & Lockhead, 1999; Needham & Modi, 1999a).

We can learn what infants encode about a briefly seen object and how this information is represented in memory by studying the kinds of "errors" that infants make in this task. If we gave infants a brief prior exposure to an object very different from the object composing the test display, we would expect that infants' segregation of the test display would be unaffected. However, as the features of the previously seen object become more similar to those of the relevant portion of the test display, we can examine the conditions under which infants respond as though they recognize one of the test objects.

The method used in these studies was the same as in the studies described in the preceding section with one exception. Our pilot testing indicated that infants who were shown a brief familiarization with a different box looked equally at the two test events in every condition we tried—no matter how similar the different boxes were in general. Looking at the two test events is the pattern of results we obtained when the infants had received either (a) no familiarization at all, or (b) familiarization with the entire test display. Thus, we speculated that the infants who received a brief prior experience with a box different from the test box (a) did not notice the connection between the familiarization box and the test display, and (b) could benefit from seeing the entire test display after seeing the familiarization box and before seeing the test event. To test this speculation, we used a three-phase procedure, with a brief familiarization trial first (typically featuring a single object), then a longer familiarization trial featuring the entire test display, and finally the test trials featuring either the move-apart or the move-together test event. We reasoned that infants may apply their prior experience to the segregation of the test display more readily if they were given the opportunity to study the test display prior to seeing the test events.

1. Change in Orientation of Box

In the first experiment, we investigated how changes in the box seen during familiarization and test would affect infants' segregation of the test display (Needham, in press). The first change we explored was a change in the orientation of the box they would see as part of the test display. During the first familiarization trial, the infants saw the test box lying on the floor of the apparatus in a horizontal orientation rather than in the vertical orientation in which it would be seen as part of the test display. After this familiarization trial and that featuring the entire display, each infant was shown one of the test events. The results showed that the mean looking time was reliably longer for the move-together than the move-apart event, indicating that infants made use of the prior experience with the test box in a different orientation to segregate the test objects into two separate units.

These results showed that a change in orientation of the object did not prevent infants' recognition of the object as part of the test display. In many ways, these results make contact with the adult literature. One possibility is that the representations infants use in object recognition are object-centered rather than viewer-centered (Biederman, 1987; Tarr et al., 1997). Another possibility is that infants
can engage in a mental manipulation of their representation of an object akin to mental rotation studied in adults (Shepard & Metzler, 1971). Both of these possibilities are still quite speculative and await further experimental exploration.

2. Changes in Features of Box

The results of the first experiment indicated that a rather pronounced change in the spatial orientation of the test box did not prevent infants’ recognition of the box in the test display. Our next question was whether infants would be similarly “liberal” in their transfer of information from one object to another object with features that differed from those of the first object. The changes introduced here were not extensive: only the background color and texture element color and shape were altered between familiarization and test. The size, viewing orientation, and placement of texture elements in the familiarization and test boxes were identical. Instead of the blue box with white squares (which they would see as part of the test display), the infants were shown a purple box with yellow circles.

The results of the first experiment showed that, after a 5-s familiarization with the purple box, the mean looking times were about the same for the two test events, indicating that the infants did not make use of this prior experience to interpret the test display. We hypothesized that the familiarization box was not similar enough to the test box for infants to apply their experience to the segregation of the test display. Therefore, in our next experiment we chose to increase the similarity between the familiarization and test boxes to see whether this change might facilitate infants’ use of their prior experience.

In the second experiment, the familiarization box was the same as the test box with one exception: the texture elements on the familiarization box were red squares, and those on the test box were white squares. The procedure was identical to the study just reported. The results showed that the mean looking times in this experiment were also equal for the two test events, again indicating that the infants did not bring to bear their prior experience with the familiarization box to segment the test display. Once again, we sought to increase the similarity between the familiarization and test boxes, so we changed the color of the familiarization box’s texture elements from red to yellow. The procedure was identical to the study just reported, and the results showed that the infants still showed no preference for either test event.

In our final study, we changed the texture elements on the familiarization box once again, hoping to make this box similar enough to the test box that infants would make use of their experience with the familiarization box to segment the test display. We changed the texture elements on the familiarization box to white circles, and put the infants through the same procedure as in the other studies. The results showed that the mean looking times for the move-together event were reliably longer than for the move-apart event, indicating that the infants perceived the test display as composed of two separate units.

Therefore, they must have applied their prior experience with the familiarization box to their segregation of the test display. Thus, when the familiarization box was only minimally different from the test box, the infants applied their experience with one to the segregation of a display containing the other. One important aspect of this finding is that it shows at least some limited ability to transfer knowledge (e.g., that this is a separate object) straight from one object to another object that they perceive to be different. One possibility is that this ability to transfer knowledge from one object to another becomes more robust with development, so that by later in the first year of life it could occur even without the support of extremely high perceptual similarity between the objects. We will return to this topic later.

3. Summary

Together, the findings of this set of experiments suggest that infants treat orientational discrepancies between familiarization and test differently from featural differences. A difference in spatial orientation that is quite noticeable (horizontal vs. vertical orientation) did not prevent infants from applying their prior experience from one object to the other. In contrast, even what seems to adults to be a very small difference in the features of the box seen during familiarization and test prevented infants from applying their prior experience with one box to segment a display containing the other box. The infants’ ability therefore seems strikingly adult-like, because for adults the features of an object—and not its spatial orientation or some other irrelevant factor—determine the object’s identity. These findings are much like those of others (e.g., Bhar & Rovee-Collier, 1994, 1996; Quinn & Eimas, 1996; Slater et al., 1991; Wilcox, in press; Wilcox & Baillargeon, 1998), and they support the idea that infants attend to and analyze object features when determining the identities of objects.

4. Changes in Features of Cylinder

Our next set of studies began an investigation of the situations within our paradigm that may reveal errors in feature integration. We were interested in determining whether recognition errors are more likely when the familiarization cylinder was the same color as the test box than when this cylinder was a different color from both test objects. This kind of error could result from a process akin to illusory conjunctions that have been found in adults (Kanwisher, 1991; Lavie, 1997; Treisman & Gelade, 1980).

As discussed in section II, illusory conjunctions are thought to occur during preattentive processing of stimuli, when the features of objects have been processed in at least a superficial way, but the features have yet to be bound to the particular object files they are associated with. After attention has been focused on the objects, though, these features are bound to the relevant object tokens. Considerable evidence suggests that infants are capable of focused attention (M. H. Johnson, 1996; Richards, 1989), but when stimulus-encoding time is limited, infants
may make analogous kinds of errors that influence their recognition judgments in the same way was illusory conjunction errors do in adults.

We have discussed the evidence indicating that infants can remember stimulus compounds (Bhatt & Rovee-Collier, 1994, 1996; Slater et al., 1991). However, whether infants use object features to form a unique representation of an object that they refer back to when seeing the same object again is a topic of some debate (Wilcox & Baillargeon, 1998; Xu and Carey, 1996). Thus, although infants may remember which features determine the unique identity of an object in some situations, in other situations they may not. They can use object features to determine object identity, for example, looking at features as a basis for recognition, but they may not succeed in noticing changes in features in all the situations in which the older child or adult would be successful.

The first situation we considered was one in which the infants received prior experience with a cylinder that was the same as the test cylinder except that it was blue—the same blue as the test box—and the test cylinder was yellow. If, after seeing the blue cylinder, the infants mistakenly believe they have had experience with either the yellow cylinder or the blue box of the test display, they may expect the display to consist of two separate pieces, just like infants who have prior experience with one of the test objects. As before, we expected that if the infants segregate the test objects, they would look reliably longer at the move-together than the move-apart test event. In contrast, if the infants regarded the blue cylinder as being too different from the yellow cylinder to help them segment the test display, they should look about equally at the move-apart and move-together test events.

In this first study, we gave the infants a 15-s exposure to the blue cylinder alone prior to testing, as prior research indicated that 15 s was (and 5 s was not) sufficient time to encode enough of the cylinder to recognize it on a subsequent encounter (Needham & Baillargeon, 1998). The results showed that the mean looking time was about equal for the move-apart and move-together events, indicating that the infants did not use the prior experience to segregate the test objects. These results suggest that after 15 s of exposure to the blue cylinder, the infants were not confused about whether they had seen a blue or a yellow cylinder—they responded as though they were sure that they had not seen part of the test display before.

In a subsequent study, we explored the consequences of reducing this familiarization time to a level that our previous research indicated was insufficient for infants to encode enough of the cylinder’s features to recognize it on a subsequent encounter. We thought this situation might be analogous to the brief stimulus presentations that have led to illusory conjunctions in adult studies. Infants were given a 5-s exposure to the blue cylinder prior to seeing the move-apart or move-together test events (Needham & Modi, 1999a). The results showed the male infants, but not female infants, looked reliably longer at the move-together than at the move-apart event, indicating that they may have thought that they had seen part of the test display before when they had not actually done so.

One possible explanation for these findings is that the brief exposure time allowed the male infants to encode the shape but not the color of the cylinder. According to this argument, a prior exposure to a cylinder of any color, as long as it was the same shape as the test cylinder, would be used by the male infants to segregate the test objects. To test this possibility, we conducted another study in which a cylinder of a different color from that seen in the test display was shown in the 5-s familiarization at the beginning of the session (Needham & Modi, 1999b). The infants saw an orange cylinder (a bright orange that was actually somewhat similar to the yellow of the test cylinder) during the brief familiarization trial.

The results indicated that neither the male nor the female infants looked reliably longer at the move-together than at the move-apart event, showing that the male infants would not use a prior experience with a cylinder of just any color to segment the test display. These results suggest that infants may experience illusory conjunctions under conditions of brief stimulus exposure, just as adults do.

These results also suggest that the male infants may have processed color information from the objects during the first 5 s of the familiarization trial, but did not link together the color and the shape of the object. By 15 s of processing, this linkage had apparently taken place. The female infants (who did not seem to experience the illusory conjunction) may process information much more quickly or much more slowly than the male infants in this situation, as their responses are consistent with both of these possibilities. More research is needed to investigate the possibilities.

Our next step in investigating illusory conjunctions in infancy will be to test the effects of prior experience with two boxes that have different components of the test cylinder’s features—for example, a blue box with yellow squares and a blue box with white squares during familiarization and a blue box with white squares in the test display. The issue is whether infants will combine features from the two boxes, as adults do in analogous situations (Lavie, 1997). We hope to explore other situations that could shed light on the question of whether infants keep track of the features of objects seen simultaneously or sequentially in the paradigm we have developed.

5. Summary

The results of the experiments summarized in this section suggest that for infants to bring to bear a prior exposure with a similar object when segregating a display, the familiarization and test objects must be highly similar. Infants seem to encode considerable information about an object when they first see it, even for as short a time as 5 s, and to require a close match between their initial and subsequent encounters with an object to believe that they have seen the object before. However, in some situations, infants may misremember having seen a certain object before when the features of the initially seen object consist of a mixture of the features of the two objects in the test display.
One may wonder how often the conditions we created in the lab would actually occur in the real world: Would infants often see either the identical object or an extremely similar object prior to seeing the object next to a novel object? If not, is the use of prior experiences to segregate objects a very common or theoretically interesting phenomenon? We wondered whether infants might overcome some of their featural specificity demonstrated in these studies if they had exposure to a collection of objects similar to those seen as part of the test display.

VIII. Categorization-Based Process

As described in the introduction, we thought it was possible that infants could make use of category knowledge to help them segment displays into individual units. The literature shows that even young infants can make categories of objects they encounter. We wondered whether infants would make use of this generalized knowledge about a group of objects to segment a display containing an object that could be considered a member of that category.

A. CATEGORIES EXPERIENCED WITHIN THE LAB

1. 4.5-Month-Old Infants

Our first step in addressing the above question was to see whether infants would make use of a prior experience with a group of objects, none of which would be an effective cue on its own, and none of which was identical to what would be seen in the test display (Needham & Lockhead, 1999). To accomplish these goals, we again used our cylinder-and-box test display and the same method described in the preceding section. In the initial 5-s familiarization trial, we presented infants a display consisting of three boxes that were ineffective in helping the infants segregate the test objects into two separate units: the purple box with yellow circles, the blue box with red squares, and the blue box with yellow squares. We knew from the studies reported in the preceding section that infants did not use any of these boxes, presented alone, to help them segment the test display. However, presenting all three of these boxes at once might lead infants to form a category of "tall, thin boxes with texture elements" that would include the test box and allow infants to see the cylinder and box as separate units.

The results were positive—the mean looking time was reliably longer for the move-together than the move-apart event, suggesting that the infants were able to form a category that (a) was general enough to include the test box as one of its members and (b) facilitated the infants’ segregation of the test display into two separate units. However, another possibility is that simply seeing any three boxes together in the familiarization trial would facilitate infants’ segregation of the test display. To test this possibility, we conducted another experiment identical to that just described except that the infants saw three identical boxes (all blue with yellow squares, the one we considered to be most similar to the test box) during the 5-s familiarization. The results showed that the mean looking times were about equal for the two test events. Together, the results of the two experiments indicate that infants can form a category of boxes that is broad enough to include the test box after being exposed to three different boxes but not three instances of one box alone.

We wanted further tests of the above conclusions, specifically the idea that infants form a general representation of a kind of box that encompasses the box seen in the test display. One way to manipulate the kind of representation infants form as a result of the familiarization trial is to make the features of all three boxes identical, as described above. Another way may be to show infants only two of the three boxes. This seemingly minor manipulation could produce an important difference in the nature of the representation infants create if the following characterization of infants’ formation of a representation is correct.

When infants are presented two different objects from the same category, they may notice the differences between the objects. However, when presented with three different objects, they may notice only not the only differences among the three objects but also the similarities, and on the basis of the similarities create a categorical representation that encompasses all three objects. If so, infants should not form a representation general enough to include the test box after seeing any two of the three different boxes described above.

To investigate this issue, infants were shown two of the three different boxes used in the first study in this section (Needham & Lockhead, 1999). The method was the same except that during the 5-s familiarization trial, the infants were shown either (a) the purple box with yellow circles and the blue box with yellow squares or (b) the blue box with red squares and the blue box with yellow squares. Results showed that the mean looking time was about equal for the move-apart and the move-together test events, indicating that they did not receive information in the familiarization trial that facilitated their segregation of the cylinder-and-box test display.

These results provide additional evidence in favor of the interpretation offered for the results of the first study in the section: Infants form a categorical representation that is general enough to include the test box when they are shown three different boxes that are all similar to the test box, but not when they are shown three identical boxes or two different boxes. Infants evidently need experience with different exemplars of a category, and they need more than one set of differences, to generalize across these differences to form a representation of the category to which these objects could belong. Infants use this categorical knowledge to determine that the test box and cylinder are separate objects even though they have seen neither of these objects before.
2. 9.5-Month-Old Infants

Another demonstration of infants’ use of category information to segment a display came in a series of studies involving older infants, who were 9.5 months old (Needham & Kaufman, 1997; Needham, Kaufman, & Modi, 1999). This line of studies began as an investigation of infants’ use of featural and spatial information to form an interpretation of a display composed of two pieces that could or could not be connected. The displays are shown in Figure 2. They were composed of two rectangular boxes arranged in depth so that the back box was visible to the right of the front box. In the parallel display, the boxes’ front surfaces were parallel to each other and the two boxes were separated in depth by a noticeable gap. In the angled displays, the edge of the back box hidden by the front box was moved toward the front box, so that the left edge of the back box could have been touching (and possibly attached to) the front box. In the Similar-angled display, the two boxes were decorated with the same color and pattern; in the Dissimilar-angled display, the two boxes were decorated with different colors and patterns.

The infants received one familiarization trial in which the stationary display was visible. In the test events, rather than moving the objects in the display, the experimenters moved a large, thin screen (35 cm square) either between the two portions of the display (screen-between event) or behind the entire display (screen-behind event). Six experimental conditions were formed by crossing the three displays with the two events. Infants were assigned randomly to these conditions in a completely between-subjects design. Our rationale was that if the infants interpreted the display as a single unit, the screen-between event would be seen as a violation of solidity, and therefore the mean looking time would be reliably longer for the screen-between than the screen-behind event. In contrast, if they saw the display as composed of two separate units, the mean looking time for the two events would be about equal.

These displays were created to explore infants’ use of two kinds of information—about the spatial relations between objects and about the features of the objects. We expected that using the spatial layout to segment the displays would lead the infants to see the parallel display as composed of two separate pieces and the angled displays as ambiguous. We also expected that using the available featural information would lead the infants to see the similar displays as composed of a single unit and the dissimilar display as composed of two separate units.

The results showed that for the infants who saw the Parallel display, the mean looking times were about the same for the screen-between and the screen-behind events, indicating that the infants used the spatial layout of the display rather than the features of the display to interpret the display as composed of two separate units. For the infants who saw the angled displays, responses to the test events depended upon whether they saw the similar or dissimilar display. For the infants who saw the Similar-angled display, the mean looking time was reliably longer for the screen-between than for the screen-behind event, but for the infants who saw

Fig. 2. Schematic drawing of the Similar parallel, Similar angled, and Dissimilar angled test displays and the screen-between and screen-behind test events used in the Needham and Kaufman (1997) studies. The effects of prior exposure to a group of displays like the Similar angled test display (that were shown to be composed of a single piece or two separate pieces) on the infants’ responses to the screen-between test event was studied by Needham, Kaufman, and Modi (1999). These studies are described in section VII.
the Dissimilar-angled display, the mean looking time was about equal for the two test events. These results suggest that the infants regarded the spatial layout of the Parallel display as unambiguous information about the display’s composition as two separate pieces. In contrast, the infants seemed to regard the angled spatial layout as ambiguous information about the display’s composition, because they made use of the color and pattern of the two portions of the display to interpret the two angled displays differently. As has been shown in previous research, infants seem to favor interpretations based on physical information—the spatial layout of the display—over interpretations based on featural information (Needham, 1997; Needham & Baillargeon, 1997).

The goal of the next study was to explore whether prior exposure to a set of displays similar to the test display would influence infants’ interpretation of test display. In this study (Needham, Kaufman, & Modl, 1999), the infants were given three familiarization trials, each featuring a display similar in color and pattern to the Similiar-angled test display and the same as this test display in size and shape. The familiarization boxes could be attached to each other to make a single object (one-object experience condition) or could be separate objects (two-objects experience condition). In each of the familiarization trials, one of the familiarization displays was deposited on the stage in such a way that its composition (as a single unit or two separate units) was clear, but once the display was in place on the stage, its spatial orientation looked just like the test display. Specifically, the experimenter deposited the connected boxes on the stage with one hand grasping one of the two-part object and deposited the separated boxes using one hand on each box and placing them on the stage one after the other. Half of the infants were in the one-object experience condition and half were in the two-object experience condition. The infants in both conditions saw the same test event—the Similar-angled display and the screen-between-event.

Because the test event depicts a movement of the screen that would be possible if one thought the test display was composed of two separate pieces, but impossible if one thought the test display was composed of a single piece, we expected that if the infants perceived the test display as composed of a single unit, they would look reliably longer at the test event than if they perceived the test display as composed of two separate units. Evidence in favor of infants’ use of their prior experience with the familiarization displays to help them segment the test display would be found if the infants who were in the one-object experience condition looked reliably longer at the test event than the infants in the two-objects experience condition. Exactly this result was obtained, even though the infants in the two-objects experience condition probably had to overcome a tendency to see the test display as a single unit (as found by Needham & Kaufman, 1997).

An additional study was conducted to determine whether the prior exposure to three different displays similar to the test display was necessary (as it was for the younger infants in the studies described in the previous section) for infants to apply their prior experience to the segmentation of the test display. This study was identical to the one just described, except that the infants saw just one of the three familiarization displays used in the prior experiment on each of the three familiarization trials. Based on our previous findings with younger infants described in the previous section, we expected that infants may not apply their prior experience with a single display to their interpretation of the test display. We were surprised to find that our results were no different from the original experiment: the mean looking time was reliably longer for the infants in the one-object experience than the two-objects experience condition.

The final study of this series was designed to determine whether infants discriminated between the familiarization display and the test display in this context. The familiarization display was light purple with bright yellow and white squares, and the test display was light blue with dark blue and white squares. Because there is evidence that infants’ color vision system functions quite well by 4 months of age (see Kellman & Banks, 1998, for a review), it seemed clear that by 9.5 months of age, infants should be capable of discriminating between displays on the basis of color alone. However, we have found no evidence that infants do discriminate between these displays in the context of this experiment. These findings suggest that infants may apply their experience with the purple box to their segmentation of the display because they do not notice that the display has changed. These findings are intriguing because they suggest a counterintuitive developmental progression in which young infants notice very small changes in an object on successive views, but older infants do not notice bigger changes. Further research is needed to explore this possible progression.

B. CATEGORIES EXPERIENCED OUTSIDE THE LAB

One way that category membership could facilitate infants’ accurate object perception is to help them identify the kinds of objects that are exceptions to the general rules they are learning to find object boundaries. For example, as a rule, objects tend to be internally uniform in shape, color, and pattern, but for some categories of objects, this heuristic would be the exception rather than the rule. For example, brushes typically have a bristle portion and a handle portion that look very different from each other but are physically connected. If one were to segment a paintbrush based on featural information alone, one would expect that the bristle portion would not be connected to the handle portion. Thus, acquiring information about the category of brushes and how they look and function would be helpful when trying to determine object boundary locations in displays containing brushes.

We wanted to investigate the development of category knowledge and infants’ use of it in segregating a display consisting of a paintbrush such as one might use
to paint the outside of a house (Needham, 1999b). The brush was composed of several distinct-looking parts: a yellow wooden handle, a bright chrome band binding the bristles to the handle, and a medium sized (6 cm × 8 cm) segment of black bristles. The brush lay against a slanting surface with the bristles down; in this orientation, the infants could see the entire brush. In the test event, a gloved hand took hold of the handle of the brush and pulled it up along the slanted surface. Half of the infants saw the brush (handle and bristles) move as a whole unit (move-together event); half saw the handle break away from the rest of the brush (move-apart event) (see Figure 3). If the infants segregated the objects on the basis of featural information alone, they should perceive the brush as consisting of more than one unit and look reliably longer at the move-together than at the move-apart event. In contrast, if the infants made use of category knowledge about brushes to segregate the objects, they should perceive the brush as a single unit and look longer at the move-apart than at the move-together test event.

Our results showed that for 12-month-old infants, the mean looking time was longer for the move-apart than the move-together test event, but for 8-month-old infants, the mean looking times were the same. These results suggest that between 8 and 12 months of age, infants acquire knowledge about brushes needed to override the interpretation of the display based solely on featural information. This knowledge allows infants to determine that the different-looking portions of the brush are actually connected to each other.

Although Carey and her colleagues have proposed that learning the words for objects facilitates infants’ ability to individuate objects (e.g., Xu & Carey, 1996), we know of no evidence indicating (and we think it is unlikely) that 1-year-old children know the words brush or paintbrush.

IX. Summary and Conclusions

We have described three ways in which infants use their prior experiences with objects when segregating displays. First, infants use their prior experiences with specific objects when segregating displays containing those objects. This effect occurs even over delays of 24 h and even when the context of the familiarization and test events are different.

Second, infants sometimes use a prior experience with an object similar to one present in the test display. Our work has shown that changes in the spatial orientation of the object between familiarization and test may be less disruptive than changes in the features of the object. This difference may signal a basic similarity in the ways in which infants and adults process object identity. At least some portions of Feature Integration Theory may be used to explain infants’ object recognition, as our findings suggest that infants use an object’s features to determine whether they have seen it before. Further evidence in this regard came from data indicating that infants may experience illusory conjunctions between features such as the shape and color of an object.

Finally, infants use a prior experience with a group of similar objects, perhaps by forming a general categorical representation that encompasses the characteristics of these objects. These categories may be formed after very brief exposures with three exemplars in the laboratory or with more lengthy exposures with any number of exemplars they encounter in their everyday experiences.

A. USE OF PRIOR EXPERIENCES VERSUS LEARNING IN GENERAL

One question about this work is how the use of prior experiences with particular objects or types of objects may be related to infants’ more general learning about the physical relations between objects and the features of objects. Extensive research has shown that infants make use of general rules to determine where object boundaries should be. For example, their physical knowledge tells them that, in general, surfaces that move together are typically part of the same object. Their featural (or configural) knowledge tells them that because objects are generally regular in shape, color, and pattern, abrupt changes in these features typically sig-
nal an object boundary. The research summarized here implies that infants use their prior experiences with specific objects and types of objects to form exceptions to these general rules. In the following section, we propose developmental process linking infants' general knowledge and the recognition- and categorization-based processes we have discussed in this chapter.

B. PROPOSED DEVELOPMENTAL SEQUENCE

We think that infants probably first develop some general-purpose heuristics such as those just described, or perhaps even more primitive rules. Presumably, the initial forms of these general rules would not be entirely accurate and could be revised as infants notice failures of the rules and gain more information about the physical or featural domain (e.g., see Baillargeon, 1995).

Failures of and exceptions to the rules may attract infants' attention and may lead infants to collect information about frequently seen objects that do not conform to general rules. For example, an infant who has not had much exposure to paintbrushes may develop knowledge about paintbrushes used during a renovation of his or her home, and may come to learn that these objects held by his or her parents do not look like they should be single objects (based on a general featural analysis), but nevertheless are single objects. At this point in the process, this knowledge could be applied to these paintbrushes in different locations within the house for as long as the infant's memory allowed, but would be limited to these particular paintbrushes (these object tokens, according to Feature Integration Theory).

The next development that occurs could be a broadening or generalization of this representation, into an object type. As infants experience more exemplars that could be grouped together as the same type, and as their compositions consistently violated what would be expected according to the more general rules, infants may develop categorical representations for types of objects such as paintbrushes or more generally brushes or even more generally things with handles. These categorical representations could help infants to be accurate in segregating previously unseen objects that fit within the perceptual representation of what an object of that type tends to look like.

These categorical representations could be a beginning part of emerging knowledge about particular types of objects. Once infants form a representation for a particular type of object, they would be able to elaborate on this basic representation, adding information about typical locations or uses for this type of object. Eimas's (1994) ideas about perceptual and conceptual representations differing from perceptual acquisition of information are consistent with our ideas about the development of this kind of knowledge.

By the time persons reach adulthood, they have established an extensive network of perceptual and conceptual representations, and they may almost automatically identify many of the objects they see. Adults' segregation of many scenes may be primarily recognition- or identification-based, and they may fall back on their more general rules only when encountering an unknown object, such as a bizarre new toy received as a baby gift or a fancy new breadmaker that needed to be disassembled for cleaning. According to this perspective, the development of a network of representations would be a key task during infancy and early childhood that could contribute in important ways to efficient and veridical interpretation of the world. One of the goals of our future research is to explore the development of this representational network.

C. VISUAL-ORAL AND VISUAL-MANUAL CONNECTIONS

We have restricted our discussion in this chapter to situations in which infants make use of visually obtained experiences when segregating displays, but infants probably could make use of, for example, orally obtained experiences and apply these cross-modally to the visual segregation of a display. Ongoing research in our laboratory indicates that infants' learning of the general featural rules they use to segment displays may be facilitated by the development of more active visual and oral exploration of objects (Needham, 1999c; Rochat, 1989).

Current research also suggests that infants make use of a visual prior experience with an object to prepare actions on the object that are appropriate (Needham, 1999a). In one study, 12-month-old infants were shown to reach differently for a display depending upon whether it had been shown to consist of a single piece or two separate pieces. This visual prior experience seemed to facilitate 12-month-old (but not 9-month-old) infants' manual actions on the display.

D. CONCLUSION

In this chapter, we have shown that beginning early in the first year of life, infants use knowledge gained about specific objects and types of objects when determining object boundary locations. That infants are not limited to interpreting displays based on featural or physical information is important, because many studies have indicated that early in life, infants' use of this knowledge leaves them with ambiguous interpretations of displays (S. P. Johnson & Aslin, 1995; Kellman & Spelke, 1983; Needham, 1998; Spelke et al., 1993). Although recent findings lead one to conclude that infants do begin to develop their general knowledge early in the first year, the use of this knowledge early in infancy may be constrained by limitations in infants' basic information-processing abilities. Thus, the ability to recognize a specific object or kind of object would play an especially important role in allowing young infants to make clear and accurate interpretations of the objects in the world. However, this ability is useful throughout the life span because segregating displays based on recognition or categorization (when possible)
should be quicker and more accurate than analyzing physical, featural, and other information in the display. As the research of Baillargeon, Spelke, and their colleagues has so elegantly shown, infants develop extensive knowledge about the physical world during the first years of life. The present research suggests that this period of time may also be critical for the formation of a knowledge base about the kinds of things that exist in the world—knowledge that mediates the process of object recognition during infancy and beyond.

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