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Infants' formation and use of categories to segregate objects

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Abstract

Four- and-a-half-month-old infants' ($N = 100$) category formation and use was studied in a series of five experiments. For each experiment, the test events featured a display composed of a cylinder and a box. Previous research showed that this display is not clearly parsed as a single unit or as two separate units by infants of this age. Immediately prior to testing, infants were shown a set of category exemplars. Knowledge about this category could help infants disambiguate the test display, which contained a novel exemplar of this category. Clear interpretation of the test display as composed of two separate units (as indicated by infants' longer looking at the move-together than at the move-apart test event) was taken as evidence of category formation and use. In Experiments 1 and 5, infants' prior experience with a set of three different boxes that were similar to the test box facilitated their segregation of the test display. Experiment 2 showed that three different exemplars are necessary: prior experience with any two of the three boxes used in Experiment 1 did not facilitate infants' segregation of the test display. Experiment 3 showed that variability in the exemplar set is necessary: prior experience with three identical boxes did not facilitate infants' segregation of the test display. Experiment 4 showed that under these conditions of very brief prior exposure, similarity between the exemplar set and test box is necessary: prior experience with three different boxes that were not very similar to the test box did not facilitate infants' segregation of the test display. Together, these findings suggest that: (a) number of exemplars, variability, and similarity in the exemplar set are important for infants' category formation, and (b) infants use their category knowledge to determine the boundaries of the objects in a display.
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1. Introduction

Roughly 50 years of research on infants' perceptual and cognitive abilities has convinced most infant researchers that the visual world of the infant is unlikely to be as blooming, buzzing, or confusing as William James once speculated. However, the young infant must still impose order on the world. The visual array must be segregated into objects, and objects must be organized into categories, about which there is much to learn. Although one might imagine that segregation is a task typically accomplished prior to categorization, this paper concerns itself with the reverse situation: when categorizing an object and making an inference from a known category can help segregate a display into separate objects.[1]

1.1. Object categorization in infancy

A large body of evidence supports the conclusion that infants can categorize forms, or treat discriminably different forms as equivalent (Bomba & Siqueland, 1983; Eimas, 1994; Greco, Hayne, & Rovee-Collier, 1990; Hayne, Rovee-Collier, & Perris, 1987; Mandler, 1998, 2000; Mandler & McDonough, 1996; McDonough & Mandler, 1998; Quinn, 1987, 1998; Quinn & Eimas, 2000; Quinn & Johnson, 2000; Younger & Cohen, 1986; Younger & Gottlieb, 1988). For example, Bomba and Siqueland (1983) presented 3- and 4-month-old infants with a series of six different exemplars of a category (such as triangles) that were formed by perturbing a canonical version of a triangle. After exposure to a series of triangle perturbations that infants could discriminate from each other, infants were presented with the canonical triangle paired with the canonical version of another shape that was involved in the same study (such as a square). The infants looked longer at the novel shape (the square, in this example) than at the shape with which they had become familiar during the first part of the study (the triangle). Perhaps the infants formed a prototype of the shape (e.g. triangle) they had seen in various perturbations, and this allowed them to view the canonical triangle as familiar even though it had never been seen (this may (Posner & Keele, 1968) or may not (Medin & Schaffer, 1978) be what adults do in this situation).

Further experiments using this same general design explored additional aspects of the context that influenced infants' categorization performance, including memory load, the number of categories represented in the exemplars (exemplars from 1 or 2 categories), and the complexity of the patterns used as stimuli. The results of Bomba and Siqueland (1983) and Quinn (1987) suggest that under conditions of low 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

[1] "Category" and "categorization" are used in many ways in the infant and adult literatures. One definition used in the adult literature specifies that a concept is a representation of a group of related items and that a category is the set of objects in the world that is picked out by the concept (Medin & Coley, 1998, p. 404). In the infant literature, the term "category" has been used to refer to both the mental representation of a class that exists in the world as well as the objects in the world picked out by that representation. Following the existing infant literature, in this paper we use the word "category" to refer to the mental representation and the extensions of that representation.

form a central representation for the category and do not maintain memory of the individual characteristic of the exemplars they used to form the category.

Interactions between memory and categories have also been studied by Rovee-Collier and her colleagues (e.g. Greco et al., 1990; Hayne, Rovee-Collier & Perris, 1987; see Rovee-Collier & Gulya, 2000 for a review of this series of studies). These researchers used a conjugate reinforcement paradigm to study how long 3- and 6-month old infants would use category information to guide their kicking responses to a set of stimuli. Their results suggest that young infants are capable of generalizing category information on the basis of physical (Hayne et al., 1987) and functional similarity (Greco et al., 1990) and that such category information remains in infant memory for as long as 2 weeks. These studies provide evidence that even young infants can use category information to guide their responses to stimuli.

Previous research has suggested that young infants are quite capable of category formation but relatively little research has looked at how infants might be able to *use* these categories to understand the visual world. One way to study category use would be to examine the types of generalizations that infants produce based on knowledge about categories. Most of this type of research has been done with older infants (9 months and up) using an inductive generalization paradigm with the logic that researchers can deduce what category knowledge infants have from the types of generalizations they produce (Baldwin, Markman, & Melartin, 1993; McDonough & Mandler, 1998). For example, when imitating a drinking behavior modeled with a dog, infants will generally imitate the drinking behavior with another animal, but not with a vehicle (Mandler & McDonough, 1996). The interpretation offered for this and other similar results is that infants apply knowledge about the categories of animal/animate and/or vehicle/inanimate to the current situation. This knowledge is assumed to be based on previous experiences with many different exemplars of animals and vehicles. The findings of these studies suggest that category representations influence infant generalization. As yet, this inductive generalization methodology has only been applied to infants 9 months of age and older (McDonough & Mandler, 1998), in part because younger infants' motor limitations prevent them from engaging in the imitation task described above.

Our studies build on this research by asking whether 4.5-month-old infants would generalize from one set of objects to another to help them resolve ambiguities in a visual scene. Using a task that is analogous to an inductive generalization task, we ask whether young infants use category-based knowledge to decode a complex visual scene. Like previous studies on inductive generalization, our task requires infants to form a category, store some information about the category, and generalize what is known about this category to a novel category exemplar. In our task, success in this process is marked by successful segregation of the test display into two separate objects.

In summary, the studies of infants' categorization of several types of stimuli (including geometric shapes, animals, and vehicles) all suggest that infants notice what changes and what does not change across sets of exemplar displays and that they use this information to form representations of these sets of items. Infants can also generalize category knowledge to novel category members, although prior research on category use has largely focused on older infants. Learning about generalization earlier in infancy is an important goal of this research (see also Bahrick, 2002), as is learning whether infants' category knowledge can facilitate infants' object segregation. In essence, this is a very short-term developmental study, because we are studying infants' creation and use of object categories within an experimental session. We believe that the processes we are studying in these experiments are important components to the development and use of infants' knowledge base during the first year of life. In the next section, the literature on object segregation in infancy is briefly reviewed.

1.2. Object segregation in infancy

A task analogous to that of organizing the world into categories is that of organizing the world into objects. One of the most fundamental tasks of vision is to transform the complex array of sensory information into an organized world composed of separate, bounded objects. If we did not segregate the world into objects, it is difficult to imagine how we could carry out even the simplest tasks. The principles of perceptual organization identified by the Gestalt psychologists, although demonstrated using two-dimensional elements, probably also help to parse the three-dimensional world at locations that correspond to the actual boundaries of objects (e.g. Wertheimer, 1950). In addition, knowledge about the kinds of objects that exist in the world is likely to be extremely helpful in parsing the objects we see. Adults' familiarity with the objects and events around them facilitates their interpretation of the environment in a variety of ways, including knowing what kinds of objects exist in the world (e.g. Dretske, 1990; Kellman, 2001; Marr, 1982) and knowing what the physical constraints are on those objects (e.g. Biederman, Mezzanotte, & Rabinowitz, 1982). The development of a knowledge base about the world and how this knowledge can help infants parse the objects they see around them is the focus of the present experiments.

Researchers have discovered much about how young infants perceive the objects in their environment, beginning with Kellman and Spelke's (1983) classic study of 4-month-old infants' perception of a partly occluded object. This study and other early work on this question led researchers to conclude that young infants used only common motion of surfaces and spatial separations between surfaces to organize displays. However, more recent research demonstrates that infants use many additional types of information, including the following: attributes such as object shape, color, and pattern; physical relations between objects; and prior experiences with individual objects either identical or similar to those in the test display (Craton, 1996; Huettel & Needham, 2000; Johnson, 1997; Johnson & Aslin, 1995; Johnson, Bremner, Slater, & Mason, 2000; Kestenbaum, Termine, & Spelke, 1987; Needham, 1998, 1999, 2000, 2001; Needham & Baillargeon, 1997, 1998; Needham & Kaufman, 1997; Needham & Modi, 1999; Quinn & Schyns, 2003; Schwartz, 1982; Slater et al., 1990; Vishton, Stulac, & Calhoun, 1998).

How prior experiences influence adults' perception of visual stimuli is currently a topic of considerable interest in the literature on adult perceptual learning. In that literature, researchers have been especially interested in the ways in which adults' rather lengthy experience with an object or set of objects influences their subsequent perception of those same objects or related objects (Edelman & Intrator, 2002; Gauthier & Tarr, 1997; Goldstone, 1995; Goldstone, Lippa, & Shiffrin, 2001; Schyns, Goldstone, & Thibaut, 1998; Schyns & Rodet, 1997; Shiffrin & Lightfoot, 1997). The current research is an initial investigation of how brief prior experiences with categories of objects influence young infants' perception of objects.

1.3. The present research

The present research is not an investigation of the stimulus factors that affect whether or how infants segregate a display into two separate objects. Rather, this research examines the effects of prior experiences with different sets of objects on infants' segregation of a single test display. After seeing a group of category exemplars, would 4.5-month-old infants generalize what they have learned about this category (in this case, information about the boundaries of the objects in the category) to a novel category member that is part of a composite test display? If infants do engage in this process of generalization, their prior experience should facilitate their parsing of the test display. Thus, the success of generalization in these studies is marked by infants' success in parsing the test display into two separate units.

The procedure used by Needham (2001) was altered for our present purposes and used in all of the experiments in this paper. In Needham's experiments, the infants were given two familiarization trials. The first consisted of a brief (5-s) exposure to a box that shared some (but not all) of the test box's attributes. The second familiarization consisted of a 10- to 30-s view of the stationary cylinder-and-box test display (see Fig. 1). Following these trials, the infants saw a test event in which a gloved hand took hold of the cylinder and moved it a short distance to the side. Half of the infants in each study saw the cylinder and box move as a single unit (Move-together event) and half saw the cylinder move away from the box, which remained stationary throughout the event (Move-apart event). The change made to this procedure for the current studies was to alter the content of the first familiarization trial. Because the present experiments investigated infants' use of category information in object segregation, infants saw multiple objects simultaneously during

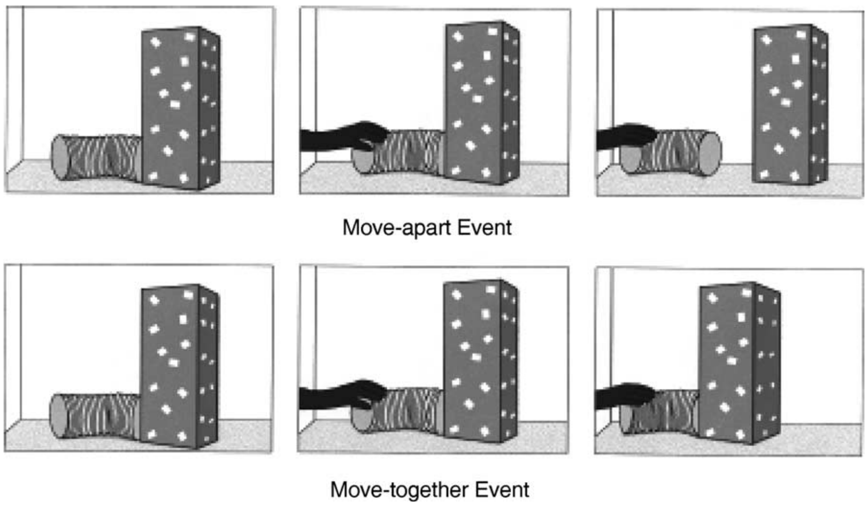

Fig. 1. Schematic representation of the test events shown to infants in Experiments 1–5.

the first familiarization trial. Because we did not want to confound amount of prior experience and number of exemplars seen prior to test, we kept the familiarization trial length at 5 s. Other than this change in the content of the first familiarization trial, the procedure followed in the present studies was identical to that used in Needham (2001). Changing the procedure in this way allowed us to study completely new questions using a well-tested methodology.[2]

In the current research, the infants saw the same test events in each of the five experiments; the only difference between the experiments was in the contents of the exemplar set shown in the initial familiarization trial. Some infants saw three boxes (Experiments 1, 3, 4, and 5), and some saw two boxes (Experiment 2). Some infants saw boxes whose attributes varied (Experiments 1, 2, 4, and 5), and some saw boxes with identical attributes (Experiment 3). Some infants saw boxes whose attributes were quite similar to the test box (Experiments 1, 2, 3, and 5) and some saw boxes whose attributes were somewhat different from the test box (Experiment 4). To anticipate our results, we find that a brief exposure to 3 boxes can facilitate infants' subsequent segregation of the test display, but exposure to 2 boxes does not. However, not just any set of three boxes creates this facilitation: there must be variability of the features of the boxes in the set and there must be similarity between the boxes in the familiarization set and the test box.

2. Experiment 1

In our first study, the infants were presented with a set of three different boxes during the first familiarization trial. The three boxes were of the same size and shape as the test box, but they varied from the test box on several dimensions—background color, texture element color, and texture element shape. The test box was blue with white squares, and the three exemplar boxes were: (a) blue with red squares, (b) blue with yellow squares, and (c) purple with yellow circles. Although prior experience with the test box itself did facilitate infants' later segregation of the test display, not one of these three boxes had that same effect (Needham, 2001). Because these altered boxes failed to function as the test box in this context, we conclude that the infants could discriminate between each box and the test box under these experimental conditions. We asked if infants would make use of the prior exposure to these boxes when seen stationary as a *group*. Would infants generalize across the different boxes and form a representation that would be general enough to include the test box? If so, we would expect the infants to parse the test display into two objects and look reliably longer at the Move-together event than at the Move-apart event. If this prior exposure was not useful in the infants' segregation of the test

[2] Although we have not counterbalanced the object grasped by the hand in the test events, we have varied the direction of hand entry (from the right or left) across experiments (Needham, 1998, 1999; Needham & Baillargeon, 1997). The results of these studies provide a clear and consistent description of infants' use of different object attributes in segregation tasks over the first year of life. Consistent results have also been obtained using a procedure in which the objects remain stationary throughout, but a screen is moved between or behind the objects (Needham & Kaufman, 1997). Together, the results of these experiments suggest that infants are engaged in assessing the composition of the display and responding on that basis, rather than on superficial aspects of the display such as which object is pulled and from which direction.

display, we would expect approximately equal looking by the infants who saw the Move-apart and the Move-together events.

2.1. Method

2.1.1. Participants

The participants were 16 healthy, full-term infants (8 females, 8 males) ranging in age from 4 months, 6 days to 5 months, 10 days ($M = 4$ months, 26 days; $SD = 11.5$). Half of the infants saw the Move-apart test event ($M = 4$ months, 24 days; $SD = 11.7$) and half saw the Move-together test event ($M = 4$ months, 29 days; $SD = 11.5$). Data from two additional infants were collected and eliminated, due to fussiness.

Infants' names in this experiment and the following experiments were obtained from the Durham County (North Carolina) vital records office and were contacted via letter and follow-up phone call. Parents were reimbursed for their travel but not compensated for their participation.

2.1.2. Apparatus

Numbers in parentheses after color descriptors refer to Munsell color chip matches. These matches were made with the objects in their positions on the apparatus, so that lighting conditions would be the same as during the experiment. The apparatus consisted of a wooden cubicle 200 cm high, 106 cm wide, and 49.5 cm deep. The infant faced an opening 56 cm high and 95 cm wide in the front wall of the apparatus. The floor of the apparatus was covered with pale blue (#2.5PB 8/2) cardboard with a clear Plexiglass cover which allowed the felt-bottomed objects to move smoothly and quietly across the apparatus floor. The side walls were painted white and the back wall was a brightly patterned contact paper.

There were two objects used in the test trials, a yellow cylinder and a blue box. The cylinder was 22 cm long and 10 cm in diameter. It consisted of a section of clothes dryer vent hose that was stuffed with Styrofoam so that it was rigid and formed a modified 'C' shape with its ends curved slightly forward. The left end of the cylinder was covered with cardboard; the right end was covered with a thin metal disc. The entire cylinder and the ends were painted bright yellow (#2.5Y 8/10). The box was 35 cm high, 13 cm wide, and 13 cm deep. It was covered with bright blue (#2.5PB 7/6) contact paper decorated with small (approximately 2 cm on a side) white squares. One corner of the box faced the infants. The left rear wall of the box (not visible to the infants) held a magnet. The cylinder lay on the floor of the apparatus with its metallic end set against the box's magnet. This made it possible for the box to move along with the cylinder when the cylinder was pulled by the experimenter's hand. The bottom surfaces of the cylinder and the box were covered with felt so they both slid smoothly and quietly across the floor. The front 2.5 cm of the cylinder's right end protruded from the box's left corner; this protrusion was designed to make clear to the infants that the cylinder and box were adjacent. In its starting position, the box was 17.5 cm from the front edge of the apparatus and 31.5 cm from the right wall; the cylinder was 28 cm from the front edge of the apparatus and 33.5 cm from the left wall. Together, the cylinder and box subtended about 30° (horizontal) and 27° (vertical) of visual angle from the infants' viewpoint.

In each test event, the cylinder was pulled to the side by an experimenter's hand wearing a 59-cm-long lavender spandex glove. The hand entered the apparatus through a wall opening that was partially hidden by a white curtain; the infant could not see the experimenter's face through this opening.

First, an infant was given a brief exposure to three boxes. Each box was identical to the test box (blue with white squares) in its dimensions and had squares or circles of approximately the same size and in the same positions as the squares on the test box. The colors and texture elements for each of the boxes were as follows: purple (#7.5P 4/10) box with yellow (#5Y 8.5/14) circles; blue (#2.5PB 7/6) box with red (#5R 4/12) squares; blue (#2.5PB 7/6) box with yellow (#5Y 8.5/14) squares. The three boxes were positioned with a corner facing the infant (as the test box would be seen later). The boxes were placed in the same depth plane that the test box would be seen, with equal amounts of space separating each box from its neighbor and the apparatus wall.

The infants were tested in a brightly lit room, with four clip-on lights attached to the back and side walls of the apparatus to provide additional light. Two wooden frames, 200 cm high and 69 cm wide and covered with blue cloth, stood on either side of the apparatus to isolate the infants from the experimental room. At the end of each trial, a white curtain was lowered to cover the opening to the apparatus.

2.1.3. Procedure

Each infant sat on his or her parent's lap in front of the apparatus. The infant's head was approximately 63.5 cm from the box. The infant's looking behavior was monitored by two observers who viewed the infant through peepholes on either side of the apparatus.[3] Each observer held a joystick connected to a computer and depressed the trigger whenever the infant attended to the events, keeping the trigger depressed for the duration of looking. Each trial was divided into intervals of 100-ms duration. For each interval, the computer determined whether the two observers agreed on the direction of the infant's gaze. Inter-observer agreement was calculated for each trial as the number of intervals in which the computer registered agreement, out of the total number of intervals in the trial. Agreement in each experiment averaged 91% per trial per infant. The input from the primary (more experienced) observer was used to determine the end of the trials.

Each infant first received one brief familiarization trial that featured the three different boxes. The boxes remained stationary throughout this trial (no hand entered so as not to distract the infants). The trial ended when the infant accumulated a total of 5 s of looking

[3] Observers were not told and could not see whether an infant had seen the Move-apart or Move-together test event until after each experimental session. Although our observers are well trained to judge the direction of the infant's gaze for each study, they are typically unaware of the specific working hypotheses for the active studies in the lab. These research assistants produce the experimental events and observe the infants, looking behavior. To assess our research assistants' knowledge of our expectations for our studies, we asked them to tell us what they thought our working hypotheses were for the 12 studies currently active in our lab. We asked them to say for each study whether they thought we were expecting the infants to look longer at the Move-apart event, longer at the Move-together event, or Neither. Because there were three choices, 33% accuracy would be expected by chance. On average, 10 of the 13 students reported having to guess at what the predictions were. The average number of correct answers was 4.58 (out of 13), which is within one standard error of the mean and therefore not significantly different from chance.

at the three boxes as a group. Following this trial, the second familiarization trial featured the stationary test display. This trial ended when the infant (a) looked away from the display for 2 consecutive seconds after having looked at it for at least 10 cumulative seconds or (b) looked at the display for 30 cumulative seconds without looking away for 2 consecutive seconds.

Following the familiarization trials, each infant saw either the Move-apart or the Move-together test event (see below for description of test events) on each of six successive trials.[4] Each test trial ended when the infant (a) looked away from the event for 2 consecutive seconds after having looked at it for at least 8 cumulative seconds (the length of one event cycle) or (b) looked at the event for 60 cumulative seconds without looking away for 2 consecutive seconds. Looking times to these six trials were used as repeated measures of infant attention to the Test Event they witnessed. Each infant completed the entire set of 6 test trials.

2.1.4. Events

2.1.4.1. Move-together event. At the start of each test trial, the curtain was raised and the infant could see the experimenter's hand on the floor of the apparatus about half-way between the cylinder and the opening in the left wall. After 1 s, the hand grasped the cylinder (1 s) and pulled it 14 cm to the left at the approximate rate of 7 cm/s (2 s). The cylinder and box moved as a single, rigid unit. The hand paused for 1 s and then pushed the cylinder and the box back to their starting positions (2 s). The hand then resumed its initial position on the apparatus floor (1 s). Each event cycle thus lasted about 8 s. Cycles were repeated without stop until the computer signaled that the trial had ended. When this occurred, a second experimenter lowered the curtain in front of the apparatus.

2.1.4.2. Move-apart event. The Move-apart event was identical to that just described except that only the cylinder moved and the box remained stationary throughout the trial. To accomplish this, the magnet was removed from inside the box and a weight was placed inside the box to prevent its movement (see Fig. 1).

2.2. Results

2.2.1. Preliminary analysis

A preliminary analysis was first conducted to determine whether there was a reliable effect of Sex on the infants' looking times at the two test events. A 2-factor analysis of covariance (ANCOVA) was conducted with Event and Sex as the between subjects factors, and looking time during the second familiarization trial (at the stationary display) as the covariate (to control for individual looking behavior differences). This analysis

[4] As in Needham and Baillargeon (1998), and all of the other research conducted on object segregation in our lab, a between-subjects design was used: each infant saw either the Move-apart or the Move-together test event. Because we assume that the infants are responding to the test event relative to their initial interpretation of the display during the familiarization trial (and we do not want to open up the possibility of elevated levels of looking being a result of surprise that the nature of the display as one or two objects changed between trials), we believe it is important to show each infant only one of the possible compositions of the display.

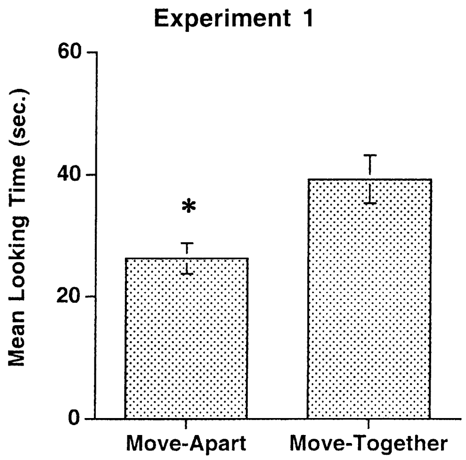

Fig. 2. Mean looking times of the infants in Experiment 1 at the two test events.

($F(1, 11) = 1.02$, $p > 0.05$) showed no significant effect of Sex on looking times at the two test events. The data were therefore collapsed across Sex for subsequent analyses.

2.2.2. Main analysis

The infants' looking times (see Fig. 2) were analyzed by means of a 1-factor analysis of covariance (ANCOVA) with Event (Move-together or Move-apart) as the between-subjects factor and looking time to the stationary test display as the covariate. This analysis yielded a significant effect of Event ($F(1, 13) = 7.21$, $p < 0.05$), indicating that the infants looked reliably longer at the Move-together ($M = 39.2$; $SD = 11.1$) than at the Move-apart ($M = 26.3$; $SD = 7.1$) test event. No other effects were significant.

2.3. Discussion

Simultaneous exposure to three different boxes, none of which on its own was an effective cue for the separateness of the cylinder and box, allowed infants to segregate the test display into two separate units. One possible explanation for this finding is that the infants formed a category on the basis of the three different boxes seen in the initial familiarization trial, and used their knowledge about the objects in this category (specifically, that they were separate entities) to determine that the box was separate from the cylinder in the test display.

Because none of the boxes was an effective cue for the separateness of the two objects in the test display when viewed alone, it seems unlikely that infants could have succeeded in segregating the test display in this experiment by focusing their attention on any one of the boxes. Rather, the infants may have gained information from the collection of three boxes (e.g. a more generalized representation) that was not available when viewing any one of the boxes in isolation.

3. Experiment 2

Although previous research ruled out the possibility that infants were paying attention to only one of the boxes presented during the familiarization period of Experiment 1, we did not know whether attending to two of the three boxes would have been sufficient to facilitate the infants' segregation of the test display. Experiment 2 addressed this question by showing infants one of the three possible pairings of the three boxes used in Experiment 1. The two boxes appearing in the first familiarization consisted of one of the following: the blue box with red squares and the blue box with yellow squares, the blue box with red squares and the purple box with yellow circles, and the blue box with yellow squares and the purple box with yellow circles.

On the basis of prior research, two of the three possible outcomes of this study seemed most likely: equal looking at the two test events (indicating that infants did not apply the prior experience to the interpretation of the test display) or a preference for the Move-together event over the Move-apart event (indicating that the infants did apply their prior experience to the interpretation of the test display).

3.1. Method

3.1.1. Participants

The participants were 36 healthy, full-term infants (18 females) ranging in age from 4 months, 7 days to 5 months, 19 days ($M = 5$ months; $SD = 10.12$). Half of the infants in saw the Move-apart test event ($M = 4$ months, 29 days; $SD = 9.31$) and half saw the Move-together test event ($M = 5$ months, 2 days; $SD = 11.0$). Data from four additional babies were collected and eliminated, two due to fussiness, one due to experimenter error and one due to poor visibility. Each infant in this sample contributed the full set of six trials to the analysis.

3.1.2. Apparatus, procedure, and events

The apparatus, procedure, and events were identical to those in Experiment 1, with the following exception. Before the test trials, rather than seeing all three boxes, the infants saw two of the three boxes: either the blue box with red squares and the blue box with yellow squares, the blue box with red squares and the purple box with yellow circles, or the blue box with yellow squares and the purple box with yellow circles. Recall that these boxes were the exact same size and shape as the test box. The two boxes were positioned on the apparatus floor so that there was about the same amount of space between the boxes as there was between each box and the nearest apparatus wall.

3.2. Results

3.2.1. Preliminary analysis

Data were analyzed as in Experiment 1. There was no significant effect of the infants' Sex on their looking times at the two Test Events ($F(1, 31) = 0.0$). The data were therefore collapsed across Sex for subsequent analyses.

3.2.2. Main analysis

The infants' looking times (see Fig. 2) were analyzed by means of a 2-factor analysis of covariance (ANCOVA) with Event (Move-together or Move-apart) and stimulus set (which set of two boxes was seen during familiarization) as the between-subjects factors and looking time to the stationary test display as the covariate. This analysis yielded no significant effect of Event ($F(1, 29) = 3.11$, $p > 0.05$), indicating that the infants looked equally at the Move-together ($M = 28.41$; $SD = 11.46$) and the Move-apart ($M = 34.95$; $SD = 10.29$) test events. No other effects were significant.

3.3. Discussion

The results of Experiment 2 show that prior exposure to any two of the three different boxes involved in Experiment 1 did not facilitate infants' segregation of the test display into two separate objects.

The conclusions of Experiments 1 and 2 are that a brief prior exposure to 3 objects, but not to 2 objects, facilitates infants' subsequent segregation of a similar test display. To lend further support to the claims that different results are obtained depending upon the number of boxes seen during familiarization, the data from Experiments 1 and 2 were analyzed together by means of a 2 (Familiarization type: three boxes or two boxes) × 2 (Test event: Move-apart or Move-together) between-subjects ANCOVA. This analysis showed a significant Familiarization type × Test event interaction, with the infants who saw three boxes in familiarization looking reliably longer at the Move-together than at the Move-apart event and the infants who saw two boxes in familiarization showing a distinctly different pattern of looking ($F = 9.51$, $p < 0.05$). Planned comparisons showed that, of the infants who saw the Move-together test event, those who had seen three boxes in familiarization looked reliably longer than those who had seen two boxes in familiarization ($t = 2.39$, $p < 0.05$). However, regardless of whether infants had seen two or three boxes in familiarization, infants looked about equally at the Move-apart test event ($t = 1.98$, $p > 0.05$). These findings lend further support to the conclusion that infants process the test events differently after seeing three boxes in familiarization than after seeing two boxes in familiarization.

Next, we turn our attention to the question of how the features of the three boxes seen in familiarization influence infants' interpretation of the test display.

4. Experiment 3

Were the attributes of the three boxes seen prior to testing in Experiment 1 important in facilitating infants' category formation and subsequent segregation of the test display? Or were the attributes unimportant compared to the number of exemplars seen? Perhaps seeing any three boxes that were somewhat similar to the test box would produce this same effect. To explore this possibility, the infants in this experiment were shown three boxes prior to seeing the test events, but these boxes were identical to each other: each box was blue with yellow squares. The boxes were identical to the test box except for texture element color (recall that the test box has white squares). Although prior experience with the test box itself did facilitate infants' later segregation of the test display, exposure to this altered box did not have the same effect (Needham, 2001). Because this altered box failed to function as the test box in this context, we conclude that the infants could discriminate between the familiarization box and the test box under these experimental conditions. If seeing three boxes with different attribute combinations is what allowed the infants to form a somewhat generalized representation in Experiment 1, then the infants in Experiment 3 should not succeed in segregating the cylinder and box test display into separate units. In contrast, if prior exposure to any three boxes facilitates infants' segregation of the test display, then seeing three identical boxes prior to test should also allow the infants to see the test display as composed of two separate units.

4.1. Method

4.1.1. Participants

The participants were 16 healthy, full-term infants (8 females, 8 males) ranging in age from 4 months, 3 days to 5 months, 20 days ($M = 4$ months, 25 days; $SD = 15.6$). Half of the infants saw the Move-apart test event ($M = 4$ months, 22 days; $SD = 14.9$) and half saw the Move-together test event ($M = 4$ months, 29 days; $SD = 16.7$). Each infant completed the entire set of 6 test trials.

4.1.2. Apparatus, procedure, events

The apparatus, procedure, and events used in Experiment 3 were identical to those in Experiment 1, with the following exceptions. Rather than seeing three boxes with different attribute combinations, the infants saw three identical boxes—each was identical to the test box except for the color of the texture elements (yellow squares rather than white squares).

4.2. Results

4.2.1. Preliminary analysis

Data were analyzed as in Experiment 1. There was no significant effect of the infants' Sex on their looking times at the two Test Events ($F(1, 11) = 1.61$, $p > 0.05$). The data were therefore collapsed across Sex for subsequent analyses.

4.2.2. Main analysis

The infants' looking times were analyzed as in Experiment 1. This analysis yielded no significant effects ($F(1, 13) = 0.12$), indicating that the infants looked about equally at the Move-together ($M = 33.7$; $SD = 9.4$) and the Move-apart ($M = 36.1$; $SD = 5.0$) test events. No other effects were significant.

4.3. Discussion

These infants who had prior exposure to three identical boxes did not segregate the test display into two separate units. Comparing these results to those from Needham (2001), we see that infants' responses to the test display were roughly the same whether the infants had prior experience with one or three copies of the box during the first familiarization trial.

These results contrasted with Experiment 1, which showed that infants who have prior experience with three *different* boxes did segregate the test display into separate units. To compare the results of Experiments 1 and 3 directly, their data were entered into a 2 (Familiarization type: Different boxes or Identical boxes) $\times 2$ (Test event: Move-apart or Move-together) between-subjects ANCOVA. This analysis produced a reliable interaction between Familiarization type and Test event ($F = 5.48$, $p < 0.05$). Planned comparisons revealed that of the infants who saw the Move-apart event, those who saw three identical boxes in familiarization looked reliably longer than those who saw three different boxes ($t = 2.15$, $p < 0.05$). However, the infants looked about equally at the Move-together event regardless of whether they had seen three identical boxes or three different boxes in familiarization ($t = 1.19$, $p > 0.05$). These findings suggest that the effect of the three different boxes familiarization on infants' looking times at the test events is more to decrease their interest in the Move-apart event than to increase their interest in the Move-together event. This pattern of results suggests that when infants look about equally at the two test events, they are looking relatively long at both events. Because they perceive the display to be ambiguous, there may be unexpected components of both events (as in Kellman & Spelke, 1983).

Together, the results of Experiments 1 and 3 are consistent with the interpretation that infants form a category representation when presented with three different exemplars of this particular kind of box. The infants use this representation to identify the test box as a member of this category, and therefore see it as separate from a novel adjacent object. Thus, with sufficient exemplars and sufficient differences between the attributes of the exemplars, infants appear able to form a generalized category representation.

5. Experiment 4

The results of Experiment 3 suggested that variation in the attributes of the boxes in the exemplar set was necessary for infants to create a representation general enough to include the test box. One could also ask whether the similarity between the exemplar set and the test box was an important factor in the facilitation effect found in Experiment 1. Much prior research on categorization in infants and adults has shown that similarity among training exemplars and between training exemplars and test items are critically important for successfully extending the newly formed category to the test item (Medin, Goldstone, & Gentner, 1993; Murphy & Medin, 1985; Oakes, Coppage, & Dingel, 1997; Tversky, 1977). In order to assess the role of this similarity in the current paradigm, the set of three boxes used in Experiment 1 was altered. In Experiment 4, we asked whether greater attribute variability among the exemplar boxes (as compared to that of the exemplar boxes used in Experiment 1) would compensate for a lower level of similarity between the exemplar set and test box. One reason to think that it might is that a more varied set of exemplar boxes could lead to the creation of a broader box category that would be more likely to include the test box.

Exemplars for this set were the same size and shape as the test box and maintained some similarity to the test box in terms of the configuration of the texture elements—all had texture elements of approximately the same size and positioning as the test box, similar to the set of exemplars in Experiment 1. However, this set contained more variability in its attributes—background color, texture element color and texture element shape. The boxes were: green with yellow triangles, purple with white squares and orange with green circles. Although prior experience with the test box itself did facilitate infants' later segregation of the test display, not one of these three boxes had that same effect (Needham, 2004). Because these altered boxes failed to function as the test box in this context, we conclude that the infants could discriminate between each box and the test box under these experimental conditions. As a set, these exemplars contained more attribute variability and were less similar to the test box than those used in Experiment 1. If infants can create a useful category after experience with this more varied set of exemplars, we should see facilitation in infants' segregation of the test display. However, if the variability is too great for infants to form a useful representation under the constraints imposed by the experimental procedure (e.g. the small number of exemplars and short familiarization time), no facilitation should be obtained.

5.1. Method

5.1.1. Participants

The participants were 16 healthy, full-term infants (8 females, 8 males) ranging in age from 4 months, 9 days to 5 months, 29 days ($M=4$ months, 26 days; $SD=16$). Half of the infants saw the Move-apart test event ($M=4$ months, 19 days; $SD=8.7$) and half saw the Move-together test event ($M=5$ months, 4 days; $SD=18.7$). Data from five additional infants were collected and eliminated: two due to fussiness, two due to poor visibility, and one due to equipment malfunction. Each infant completed the entire set of 6 test trials.

5.1.2. Apparatus, procedure, events

The apparatus, procedure, and events used in Experiment 4 were identical to those in Experiment 1, except for the specific boxes used in the first familiarization trial. The boxes were: green (#2.5G 5/12) with yellow (#5Y 8.5/14) triangles, purple (#7.5P 4/10) with white squares and orange (#10R 6/12) with green (#2.5G 5/10) circles.

5.2. Results

5.2.1. Preliminary analysis

Data were analyzed as in Experiment 1. There was no significant effect of Sex on their looking times at the two Test Events ($F(1,11)=0.09$, $p>0.05$). The data were therefore collapsed across Sex for subsequent analyses.

5.2.2. Main analysis

The infants' looking times were analyzed as in Experiment 1. There was no significant effect of Test-Event ($F(1,13)=0.24$), revealing that infants looked about equally at the Move-together ($M = 39.9$; $SD = 10.6$) and Move-apart ($M = 37.2; SD = 13.7$) test events. No other effects were significant.

5.3. Discussion

Exposure to this set of boxes did not facilitate infants' subsequent segregation of the test display. These results suggest that attribute variability in the initial exemplar set is not in itself sufficient to facilitate later parsing of the test display, at least not under these conditions (e.g. the small number of exemplars and short familiarization time). When combined with the results of Experiment 1, the pattern of results indicates that similarity between the exemplar set and the test box is also necessary to allow infants to form a representation of a category that includes the test box. Although the exact nature of the category representation being formed is (obviously) unknown, it is intriguing to speculate about what information seems to be represented. When infants were confronted with only a single exemplar, information about all three attributes—background color, and texture element shape and color appeared to be represented, because a change in almost any attribute was sufficient to preclude generalization from prior experience to the test event (Needham, 2001). It seems reasonable to conclude that all three of these attributes are present in the category representation infants form when faced with the three exemplar boxes.

Although we do not believe that the representation infants form is a simple tallying of the attributes of the exemplars presented, we found such a tally to be useful when trying to assess the overall similarity of a *set* of boxes to the test box (we also acknowledge that computing similarity is a notoriously complicated topic, as evidenced by many different mathematical and theoretical treatments such as Medin & Schaffer, 1978; Nosofsky, 1992). For each exemplar set, 'modal attribute values' were calculated by determining which values were most frequent for each attribute (background color, texture element color, and texture element shape) in a given exemplar set. For example, the set of boxes from Experiment 1 (purple with yellow circles, blue with red squares, and blue with yellow squares) produced the following modal values: blue for the background color, yellow for the texture element color, and square for the texture element shape (see Table 1 for the attributes of the boxes of each set, as well as the resulting modal attribute values).

The importance of *variability* in the exemplar set can be seen by noting that the exemplar set used in Experiment 1 facilitated infants' subsequent segregation of the test display, even though the modal attribute values for this set were a blue background and yellow squares. We know from the results of previous research (Needham, 2001) and Experiment 3 in this paper that prior experience with either one or three identical copies of a box displaying this combination of attributes, blue background with yellow squares, did not facilitate infants' segregation of the test display. Thus, variability within the exemplar set seems to be important, and infants must be extracting more from the exemplar set than just the modal attribute values.

The importance of *similarity* between the exemplars within the set as well as between the overall set and the test box can be seen by noting the set of three boxes that did not facilitate later object segregation performance. The set of exemplar boxes for Experiment 4 produced no modal attribute values because there was no overlap in the values of any of

Table 1
Features of the boxes and 'modal box' that can be derived from each familiarization box set (see text), listed by experiment

	Background color	Texture/pattern color	Texture/pattern shape	Modal box
Test box	Blue	White	Squares	
Experiment 1	Purple	Yellow	Circles	Blue box with yellow squares
	Blue	Red	Squares	
	Blue	Yellow	Squares	
Experiment 2	Blue	Red	Squares	Blue box with colored squares
	Blue	Yellow	Squares	
	Blue	Red	Squares	Colored box
	Purple	Yellow	Circles	
	Blue	Yellow	Squares	Colored box with yellow texture elements
	Purple	Yellow	Circles	
Experiment 3	Blue	Yellow	Squares	Blue box with yellow squares
	Blue	Yellow	Squares	
	Blue	Yellow	Squares	
Experiment 4	Green	Yellow	Triangles	Colored box
	Orange	Green	Circles	
	Purple	White	Squares	
Experiment 5	Green	White	Triangles	Colored box with white squares
	Blue	Red	Squares	
	Purple	White	Squares	

Experiments containing familiarization sets that led to successful segregation of the test display are shown in bold.

the exemplar attributes (this of course would likely change with exposure to more exemplars). The overall similarity between the exemplar set and the test box (defined as the overlap between the exemplar set modal values and the attributes of the test box) was also low. Thus, it seems that some variability in the exemplar set and some similarity within this set and between the set and the test box are necessary for infants to apply their prior experience with the set to their segregation of the test display.

6. Experiment 5

Taken together, the results from the previous studies suggest that the type of prior experience conducive to successfully parsing the test display would be with a set of three box exemplars that contain variability in their attributes as well as similarity to the test box. To test this conclusion, a new set of boxes that met these conditions was constructed.

The set of exemplar boxes used in this experiment consisted of the following three boxes: green with white triangles, blue with red squares and purple with white squares. Although prior experience with the test box itself did facilitate infants' later segregation of the test display, no one of these three boxes had that same effect (Needham, 2004). Because these altered boxes failed to function as the test box in this context, we conclude that the infants could discriminate between each box and the test box under these experimental conditions. These boxes were all the same size and shape as the test box, and produced the following modal attribute values: white squares on a colored background. Obviously, the attributes of the test box—blue background with white squares—are quite similar to these modal values.

6.1. Method

6.1.1. Participants

The participants were 16 healthy, full-term infants (8 females, 8 males) ranging in age from 4 months, 7 days to 5 months, 26 days ($M = 5$ months, 8 days; $SD = 15.2$). Half of the infants saw the Move-apart test event ($M = 5$ months, 7 days; $SD = 10.8$) and half saw the Move-together test event ($M = 5$ months, 8 days; $SD = 19.4$). Data from six additional infants were collected and excluded, three due to computer related malfunctions, two due to systematic disagreement between the two observers and one due to experimenter error. Each infant completed the entire set of 6 test trials.

6.1.2. Apparatus, procedure, events

The apparatus, procedure, and events used in Experiment 5 were identical to those in Experiment 1, with the following exceptions. Infants saw three boxes with varied attribute combinations that yielded modal attribute values similar to the attribute of the test box. The boxes were green (#2.5G 5/12) with white triangles, blue (#2.5PB 7/6) with red (#5R 4/12) squares and purple (#7.5P 4/10) with white squares.

6.2. Results

6.2.1. Preliminary analysis

Data were analyzed as in Experiment 1. There was no significant effect of the infants' Sex on their looking times at the two Test Events ($F(1, 11) = 1.1$, $p > 0.05$). The data were therefore collapsed across Sex for subsequent analyses.

6.2.2. Main analysis

The infants' looking times (see Fig. 3) were analyzed as in Experiment 1. This analysis yielded a significant effect of test event ($F(1, 13) = 7.79$, $p < 0.05$) indicating that infants looked reliably longer at the Move-together ($M = 39.7$; $SD = 10.6$) than at the Move-apart ($M = 26.1$; $SD = 6.3$) test events.

6.3. Discussion

After seeing the boxes in the exemplar set described above, the infants looked reliably longer at the Move-together than at the Move-apart test events, indicating that they were

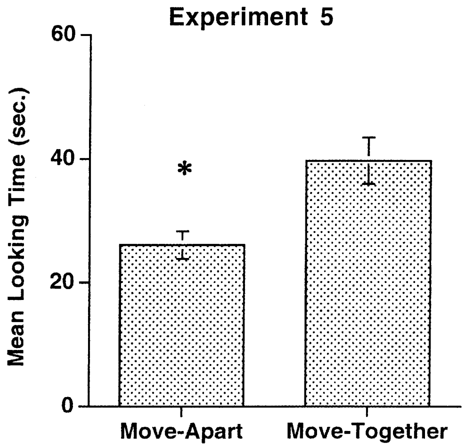

Fig. 3. Mean looking times of the infants in Experiment 5 at the two test events.

able to segregate the test display into two separate objects. A modal representation of the set of exemplars used in this study produces a variably colored box with white squares: a representation that is quite similar to the test box. Given the results of the previous experiments, it seems likely that it was the combination of variability within the exemplar set and similarity to the test box that rendered this prior experience useful for the segregation of the test display.

To compare the results of Experiments 4 and 5 directly, their data were entered into a 2 (Familiarization type: Less similar or More similar boxes) × 2 (Test event: Move-apart or Move-together) between-subjects ANCOVA. This analysis did not produce a significant interaction between Familiarization type and Test event ($F = 2.01, p > 0.05$). Thus, these results support the idea that the differences between the effects of the familiarization sets used in Experiments 4 and 5 were more quantitative than qualitative.

7. General discussion

This research provides evidence that 4.5-month old infants are capable of forming a category based on experience with similar objects, and that they can use information about objects in that category (in this case, what the physical boundaries are) to inform their expectations about a novel member of the category. Specifically, we explored the conditions that facilitated category formation by young infants and found that, like adults, young infants' category formation was affected by exemplar set similarity and variability (Experiments 1, 3, 4 and 5) as well as by number of exemplars (Experiment 2). Further, we demonstrated that when the conditions for category formation were met, young infants could use the category to guide their generalizations about a similar novel object (Experiments 1 and 5).

In this research, infants were presented with a display that prior research determined was ambiguous in composition for infants this age (Needham & Baillargeon, 1998).

The experience infants received at the beginning of the session were varied across experiments to determine under what conditions infants would use this experience with a group of objects to help them solve it. In essence, we studied perceptual learning in infants by looking at their *formation* and *use* of category information to segregate objects.

7.1. Category formation

What do we know about the circumstances under which infants will form a representation that is useful for object segregation in this context? The present research identifies three factors that affect this process in important ways: similarity between the exemplar set and the test object, variability in the exemplar set, and number of boxes in the exemplar set. These factors are likely to be interdependent, as indicated by the connection between variability and similarity elaborated in the Discussion of Experiment 4.

Our results suggest that the similarity between the exemplar set and the test object is critically important for infants to form a useful representation. When similarity was relatively high (as in Experiments 1 and 5), infants' segregation of the test display was facilitated; when similarity was relatively low (as in Experiment 4), infants' segregation was not facilitated. Low similarity among category exemplars may be problematic in this context because exposure time and number of exemplars is very low. These results are consistent with the existing literature on categorization in adults. In many theories of categorization in adults, the perceived similarity between the experienced exemplars and a novel exemplar is the critical piece of information that determines whether the novel exemplar will be included in the category (e.g. Medin et al., 1993; Mervis & Rosch, 1981; Murphy & Medin, 1985).

The second factor that the present research identifies as important is variability in the exemplar set. At least some variability in the exemplar set seems to be important, as segregation was not facilitated for infants who saw an exemplar set with three identical boxes (Experiment 3). When infants were shown three different exemplars, they could form a representation that was useful for segregating the test display when variability among these exemplars was relatively low (as in Experiments 1 and 5), but not when variability was relatively high (as in Experiment 4). This pattern of results is consistent with what is known about the role of variability in the exemplar set in infant categorization. For example, 7-month-old infants recognize correlated stimuli when all of the salient attributes are correlated, but the presence of an extra variable attribute interfered with these infants' (but not older infants') detection of the correlation (Younger & Cohen, 1986). Another study with young infants revealed that although infants as young as three months of age could detect regularities across pattern variations, the particular regularities recognized changed with age such that older infants were able to recognize more complex regularities than were younger infants (Younger & Gottlieb, 1988). Studies with adults also suggest a complex role for variability, one that shifts with changing task demands (Elio & Anderson, 1984). Combined with our results, these previous findings suggest a central, but complex, role for variability in the process of infant categorization. It is possible that this role changes with development, task demands, or both of these factors.

Finally, our results show an effect of the number of boxes in the exemplar set. Under the conditions of our study, three exemplars did allow category formation in some cases, but two exemplars did not. This finding suggests that three exemplars may represent a lower limit for the number of exemplars necessary to create a useful category representation, at least given the constraints of this experimental setting. Clearly, the number of exemplars needed to form a category is likely to be dependent on the specific context as well as the specific exemplars to which the infants are exposed. For example, if the number of boxes in the exemplar set used in Experiment 4 had been increased from 3 to 6, and if more time had been allowed for processing these exemplars, perhaps the infants could have formed a useful category despite the variability in the exemplar set. This idea receives some support from earlier adult work showing that the impact of variability within a category training set was mediated by the number of exemplars in the set (Homa & Vosburgh, 1976). The relation found in this study was that high variability in a small exemplar set was detrimental to later category formation, but high variability in a larger set was beneficial.

Why would three exemplars be so much better than two exemplars for category formation? Another way of thinking about this idea is suggested by Huettel and Lockhead (1998). According to their view, participants in an experimental task (infants, in our case) may actively seek out the regularity present in the displays. In our task, infants would compute a set of similarities and differences for each novel pairing of objects they see. With two objects present, there are two sets of attributes to compare. Infants notice that the objects are either the same or different on those attributes, and processing goes no farther. However, with three objects, there are three possible combinations of comparisons to make (A to B, B to C, and A to C). Given a larger set of comparisons, processing might go farther, leading to the formation of a more abstract representation. Similarities across the three sets of comparisons between the objects might outnumber the differences (e.g. all three have the same shape, one has yellow texture elements, two have white texture elements), making the similarities more noticeable, and facilitating category formation. We plan to assess this possibility in future work.

Clearly, a satisfactory answer to this question will depend on additional studies to explore more components of this situation; minimum conditions for categorization have not been a popular topic of study for adult or infant categorization researchers. The answer to this question is likely to depend on such specifics as duration of the familiarization procedure, the contexts in which exemplars are experienced, and the age of the observers. Understanding the underlying processes for this phenomenon would have implications for our understanding of categorization in infancy (and possibly our understanding of categorization in general).

7.2. Category use

Our studies do add to what is known about category formation in infancy, but the more unique contribution is to show how infants **use** categories to resolve ambiguities in the perceptual world—infants interpret the test display as a cylinder and box because of a set of similar boxes they had seen before. Contrary to some accounts of early conceptual and linguistic development (Xu & Carey, 1996; Xu, Carey, & Welch, 1999), knowing a label for these boxes is not necessary for the facilitative effects of this prior experience. We believe that the present data and other data (Munakata, Santos, Spelke, Hauser, & O'Reilly, 2001; Needham & Ormsbee, 2004; Wilcox, 1999;

Wilcox & Baillargeon, 1998a,b) provide evidence against the notion that language is the *critical* link between infants' prior knowledge and the application of that knowledge to perceptual and conceptual tasks. Indeed, it is not clear how infants could learn the words for things if these words were required to perceive and represent the objects in the first place (see Murphy, 2002). Rather, exposure to a coherent set of category exemplars appears to be sufficient for infants to form representations for use in a number of different tasks.

7.3. Object categories and concepts

Our findings suggest that "kind" concepts could have visual beginnings, so that even after a very brief visual exposure to a group of similar objects, there is a visual answer to the question "What kind of things are these?" In the present research, the answer would be a non-verbalized form of: "Tall rectangular boxes with shaped texture elements." Such visually based (and yet abstract) representations could facilitate infants' performance of many tasks, including the object segregation task in the present research. Although the uses for these categories would be limited to begin with, these early concepts would be elaborated quickly with additional experience-based information and would become useful for a wider array of tasks with development. Supporting this view are data showing that a 2-min exposure to the three boxes used in Experiment 5 facilitates infants' segregation of the test display 3 days after they received the experience (Dueker, Modi, & Needham, 2003). Thus, even though the experiences are brief, the representations left behind are long-lasting and can therefore be considered an addition to the knowledge base. Thus, the current results give us insight into the fascinating question of how infants develop a knowledge base.

As researchers studying adult cognition have argued, the distinctions between perceptual and conceptual processing are not as clear-cut as they may seem. The elegant work of Goldstone and his colleagues has shown that adults' concept-learning in a given domain changes their perceptual judgments in that domain (Goldstone, 1995; Goldstone et al., 2001; Goldstone & Steyvers, 2001). Representations that may seem abstract often have a strong visual component, and representations that may seem closely tied to their sensory origins are not as concrete as one might expect (see Goldstone & Barsalou, 1998). Thus, drawing a clear line of demarcation between "perception" and "cognition" or even between "sensory" and "abstract" is not at all straightforward. Even in adulthood, the differences between the two ends of the perception–conception continuum may be much smaller than our intuition would suggest. Given the continuities between adult and infant cognition pointed out by many researchers (e.g. Eimas, 1994; Bonatti, Frot, Zangl, & Mehler, 2002; Rovee-Collier & Gulya, 2000) and given the findings of the present research, we consider it unproductive to engage in arguments about whether infants accomplish various cognitive tasks via low-level perceptual processes that are unaffected by higher level knowledge (e.g. Bogartz, Shinskey, & Speaker, 1997; Haith & Benson, 1998). We think that infancy researchers should be wary of embracing the perception–conception distinction in their own work, because it is not clear whether infants or adults really engage in such strictly perceptual processing as conceived by these researchers.

7.4. Final comments

The results of these experiments suggest that infants' perceptual learning facilitates their interpretations of objects and provide us with some insight into the mechanisms that are used to build the knowledge base. Researchers such as Eimas (1994) have long argued that constraining our ideas about underlying mechanisms in ways that stress continuity between infant and adult and between perceptual and conceptual is advantageous, and we agree. It is well-accepted that adults' interpretations of currently visible information is influenced by the observer's prior experiences (e.g. Biederman et al., 1982; Dretske, 1990; Goldstone, 1995; Marr, 1982; Rock, 1975, 1983; Shepard, 1983; Shiffrin & Lightfoot, 1997). Our results suggest that there are important continuities between infant and adult cognition in this regard. It is striking that even though the infant knowledge base must be quite limited compared to that of adults', infants' reliance on prior knowledge to help them solve various tasks is prevalent in the literature on infant cognition (e.g. Baillargeon, 1999; Mandler, 1998; Spelke, Breinlinger, Macomber, & Jacobson, 1992). Infants must rely upon their own experiences to come to know the world. They actively process these experiences and make use of what they know to help them figure out what they see.

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