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5

Experience Primes Infants to Individuate Objects

Illuminating Learning Mechanisms

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The visual world provides infants with a wealth of information about objects and their physical properties. At the same time, as infants and objects move about in the world, visual contact is frequently lost and then, later, regained. For example, a toy train passes through a tunnel and emerges at the other side, or a favorite blanket slides behind the car seat and later moves back into view. The dynamic nature of the visual world presents infants with the challenge of determining whether an object currently in view is the same object or a different object than seen before. The outcome of this process determines how infants perceive, think about, and act on objects. Given the importance of object individuation to human cognition, researchers have invested a great deal of energy to identify the origins and development of this capacity.

Initial studies focused on the type of information infants use to individuate objects and how this changes during the first year of life. The collective outcomes of this research can be summarized in the following way. First, spatiotemporal information is fundamental to the individuation process. For example, by 3.5 months, infants use discontinuities in speed or path of motion to signal the presence of distinct objects (Baillargeon & Graber, 1987; Spelke, Kestenbaum, Simons, & Wein, 1995; Aguiar & Baillargeon, 2002; Wilcox & Schweinle, 2002, 2003). Second, young infants can also use featural information to individuate objects, but this capacity is not as well developed. For example, by 4.5 months infants use form features (e.g., shape, size), but it is not until much later that infants use surface features (e.g., color, pattern, luminance) as the basis for individuating objects (Wilcox, 1999; Tremoulet, Leslie, & Hall, 2001; Woods & Wilcox, in press). Third, and perhaps most important, studies have revealed that infants' capacity to individuate objects is not "all-or-none" but is supported in some conditions and not in others (Xu & Carey, 1996; Wilcox & Baillargeon, 1998a; Tremoulet et al., 2001; Wilcox & Chapa, 2002; Wilcox & Schweinle, 2002, 2003; Wilcox & Chapa, 2004; Wilcox, Woods, Chapa, & McCurry, 2007).

More recently, attention has shifted toward understanding the reasons that infants are more sensitive to some types of information than to others and how infants come to identify new sources of information as relevant to the individuation problem. One approach we have taken is to identify experiences that can alter infants' sensitivity to surface features. The conditions under which these experiences are most effective can reveal important information about the nature and content of infants' object representations, how infants' use these representations, and the cognitive and/or learning mechanisms that govern changes in infants' individuation capacities. This chapter focuses on this body of research.

ASSESSING OBJECT INDIVIDUATION IN INFANCY

Before we review this research, however, a discussion of the methods that we use to assess object individuation in infancy is warranted. A number of violation-of-expectation tasks have been developed to assess object individuation. One task that is particularly sensitive to developmental changes in this capacity is the narrow-screen task (Wilcox & Baillargeon, 1998a, 1998b; Wilcox, 1999; Woods & Wilcox, 2006). In the narrow-screen task, infants participate in a two-phase procedure that consists of a familiarization phase and a test phase. In the familiarization phase, infants are presented with a familiarization event in which two featurally distinct objects (e.g., a ball and a box) emerge successively to opposite sides of a wide yellow screen. The two objects move in the same depth plane (i.e., along the same axis) so that it would not be possible for them to pass each other behind the screen without colliding. The yellow screen is wide enough to hide both objects, side by side, at the same time. The purpose of the familiarization trials is to acquaint the infants with the objects they will see in the test trials. In the test phase, infants are presented with a test event (Fig. 5–1) that is identical to the familiarization event except that the wide yellow familiarization screen is replaced with a blue screen that is either too narrow (narrow-screen event) or sufficiently wide (wide-screen event) to hide both objects simultaneously. If infants (a) perceive the different-features event as involving two separate and distinct objects and (b) recognize that both objects can fit behind the wide but not the narrow screen, then they should find the narrow- but not the wide-screen event unexpected. Hence, longer looking at narrow- than wide-screen events is taken as evidence for object individuation.

In some of our first studies using the narrow-screen task (Wilcox & Baillargeon, 1998a, 1998b) we found that when the objects seen to each side of the screen varied on several feature dimensions, including shape, color, and pattern, infants 4.5 to 11.5 months successively individuated the objects (i.e., looked reliably longer at the narrow- than at the wide-screen test event). In control studies, (a) the objects were made sufficiently small to fit behind either the narrow or the wide screen or (b) the same object was seen to each side of the screen.

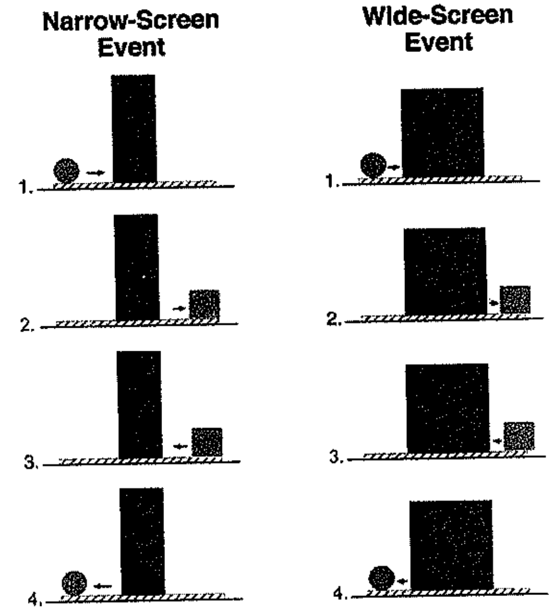


Figure 5–1. The test events of the narrow-screen task developed by Wilcox and Baillargeon (1998a, 1998b). Steps 1–4 repeat until the end of the trial.

In the control studies, infants looked equally at the narrow- and wide-screen test events, supporting Wilcox and Baillargeon's (1998a, 1998b) interpretation of the narrow-screen results. Finally, subsequent research using a different violation-of-expectation task provides converging evidence for the conclusion that young infants use featural differences to signal the presence of distinct objects (Wilcox & Baillargeon, 1998a; Wilcox & Schweinle, 2002).

Despite converging evidence from control studies and from other violation-of-expectation tasks, questions have been raised about the extent to which the narrow-screen task assesses object individuation in infants. For example, Xu and Carey (2001; Xu, Carey, & Quint, 2004) have offered an alternative interpretation for infants' looking longer at narrow- than at wide-screen events that does not involve object individuation. The logic of this account rests on a perceptual phenomenon called the tunnel effect. Under select conditions, adults perceive different-features events as involving a single object that changes it appearance when out of view. Xu and Carey have suggested that the conditions of the narrow-screen event support the tunnel effect. In this view, infants look longer at different-features narrow-screen events because they (1) perceive the event as involving a single object and (2) find changes in the objects' appearance, as it moves back and forth behind the screen, unexpected. Wide-screen events do not support the tunnel effect; that is why infants do not demonstrate prolonged looking to different-features wide-screen events. Although a plausible hypothesis, data collected in our lab using a different methodology argue against this interpretation of the narrow-screen results.

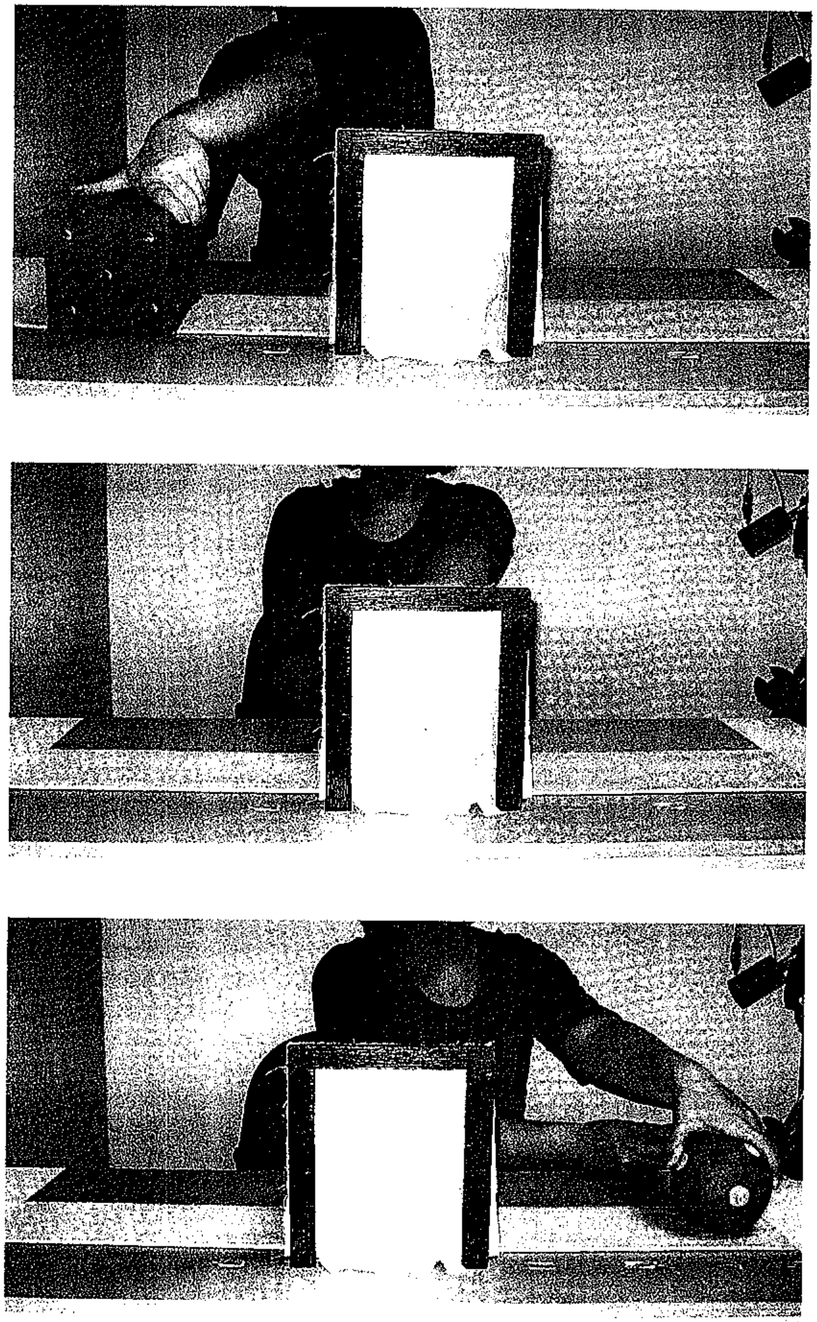
Recently, we have designed a new task, one that depends on reaching rather than looking behavior, to assess competing interpretations of the narrow-screen results (McCurry, Wilcox, & Woods, 2008). In one experiment, infants aged five to seven months (*M* age = six months, seven days) saw a test event in which a box disappeared behind the left edge of a screen and a ball emerged at the right edge (Fig. 5–2). The screen was either narrow or wide and consisted of a wood frame to which multiple layers of fringe were attached. The fringe occluded the area behind the screen. Before the test trials, infants were shown that the fringe allowed hands to easily pass through, and the infants were allowed to reach for objects through the fringed screen. After the ball came to rest at the right edge of the platform, the platform was moved forward so that the screen was directly in front of the infant; the infant was then allowed to reach. The event parameters (e.g., the size of the objects and the width of the screens, the rate at which the objects moved, the length of the trajectory, the time the objects were occluded) were identical to those used in our narrow-screen violation-of-expectation experiments (Wilcox & Baillargeon, 1998a, 1998b; Wilcox, 1999). If infants use the featural differences between the box and the ball to signal the presence of distinct objects and recognize that one of the objects (i.e., the box) is hidden behind the screen at the end of the event sequence, they should spend significantly more time reaching through the fringed screen than reaching for the ball at the end of the platform. In contrast, if infants interpret the event as involving a single object, which changes its appearance when behind the screen, they should spend more time reaching for the visible ball at the end of the platform than reaching through the fringed screen. The results revealed that the infants spent significantly more time reaching through the fringed screen than reaching for the ball at the end of the platform, as if they were searching for the hidden box. In addition, 23 of the 28 infants tested (83%) demonstrated this pattern of reaching. Most importantly, the reaching behavior of the infants in the narrow- and wide-screen conditions did not differ reliably. Together, these results suggest that the infants interpreted the box–ball event as involving two objects and that this interpretation did not vary by screen width.[1]

There is an alternative interpretation of the box–ball results, however, that should be considered. It is possible that the infants reached more to the screen than to the ball because the screen was closer to them and they found it more interesting, and not because they were searching for the box behind the screen. To assess this interpretation, another group of five- to seven-month-olds (*M* age = 6 months, 8 days) were tested using the procedure described above with one difference: A ball was seen to both sides of the screen. If the infants who saw the box–ball event spent more time reaching to the screen than to the ball because the screen was closer and more interesting, then the infants who saw the ball–ball event should also reach more to the screen than to the ball. In contrast, if the infants who saw the ball–ball event spent more time reaching to the screen because they were attempting to retrieve the box that was hidden behind the screen, then the infants who saw the ball–ball event should direct their reaching behavior to the visible ball (since the screen does not hide a second object). The results revealed that the infants spent significantly more time reaching for the ball than for the screen. In addition, 24 of the 28 infants tested (86%) reached more often to the ball than to the screen. These results suggest two conclusions. First, the infants interpreted the ball–ball event as involving a single object, a ball that moved behind the screen and came to rest at the right edge of the platform. Second, the reaching behavior of the ball–ball infants is better explained by a directed search for the hidden box than as an interest in the fringed screen.

In summary, the outcome of these search experiments provides converging evidence for the conclusion that the narrow-screen violation-of-expectation task assesses infants' capacity to individuate objects and not lower-level perceptual processes, such as the tunnel effect. This result is important because most of the experiments described in this chapter use the narrow-screen task to assess object individuation. The outcome of these search experiments also suggests that the fringed-screen task is a sensitive and reliable measure of object individuation in infancy. Hence, we now have another method with which to investigate developmental changes in infants' individuation capacities.

INFANTS' DIFFERENTIAL SENSITIVITY TO FORM AND SURFACE FEATURES

At the same time that our investigations have indicated that young infants use featural information to individuate objects, they have also revealed that infants are not equally sensitive to all types of featural information. Notice that in the box–ball and ball–ball studies described so far, the objects seen to each side of the screen differed on many feature dimensions. Object features can be divided into two broad categories: those features that specify the three-dimensional form of an object and those that convey information about surface properties. We have systematically investigated infants' sensitivity to form and surface features during the first year of life using the narrow-screen task (Wilcox, 1999; Wilcox et al., 2007 [Experiment 1]; Woods & Wilcox, 2006). In these experiments, the objects seen to each side of the screen varied on only one feature dimension at a time (e.g., the objects differed in only shape or color). The results of these studies revealed that by 4.5 months, infants use form features, such as shape or size, as the basis for individuating objects. In contrast, it is not until later in the first year that infants use surface features, such as pattern, color, or luminance. Most relevant to this chapter is the development of infants' sensitivity to color information. We have found that it is not until 11.5 months that infants use color differences to individuate objects. These data are consistent with data obtained in studies of object segregation and identification, where an advantage for form over color information has also been observed (Needham, 1999; Tremoulet et al., 2001). This pattern of results is intriguing because by 11.5 months, infants can perceive color differences, yet they fail to draw on these differences to individuate objects.



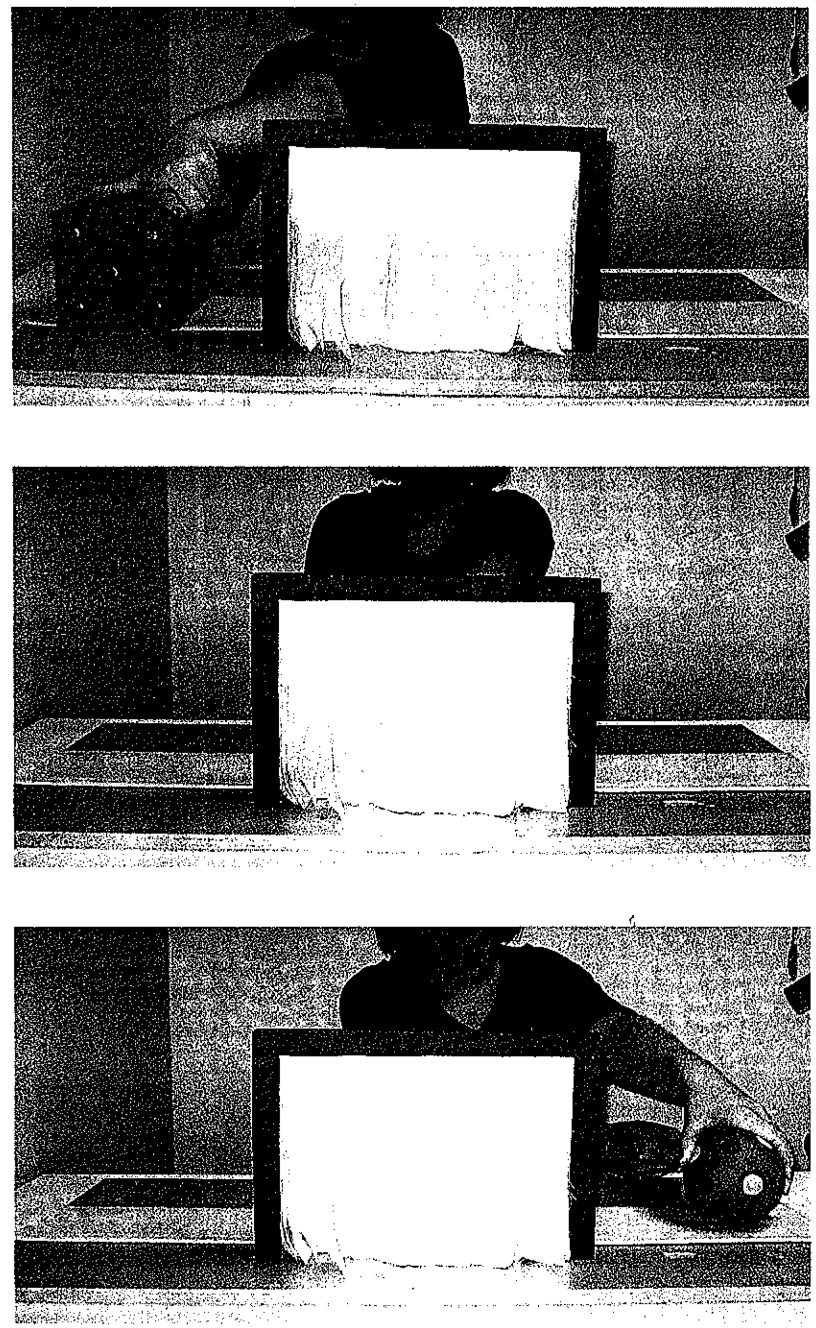


Figure 5–2. The ball–box test events of the search task of McCurry, Wilcox, and Woods (2008).

EXPLAINING INFANTS' GREATER SENSITIVITY TO FORM THAN TO COLOR INFORMATION

There are probably several factors that contribute to infants' greater sensitivity to form than color information. It is likely that the developmental hierarchy favoring form features reflects, at least to some extent, the nature of the developing visual system. Because color vision is initially quite poor (Peeples & Teller, 1975; Adams, Courage, & Mercer, 1994; Adams, 1995; Adams & Courage, 1998; Teller, 1998), young infants have difficulty getting good information about color. On the other hand, infants' sensitivity to areas of high contrast (Adams & Maurer, 1984; Stephens & Banks, 1987) and to motion-related information (Kellman, 1984; Slater & Morison, 1985; Slater, Morison, Town, & Rose, 1985; Kellman & Short, 1987; Slater, Mattock, & Brown, 1990; Arterberry & Yonas, 2000) presents even young infants with many opportunities to gather information about object form. However, visual maturation cannot fully explain the developmental hierarchy favoring form features. First, infants are sensitive to color differences long before they use those differences to individuate objects. By 4.5 months, infants detect, categorize, and demonstrate memory for color information (Bornstein, 1975; Bornstein, Kessen, & Weiskopf, 1976; Moskowitz-Cook, 1979; Banks & Salapatek, 1981; Powers, Schneck, & Teller, 1981; Hayne, Rovee-Collier, & Perris, 1987; Catherwood, Crassini, & Freiberg, 1989; Brown, 1990; Banks & Shannon, 1993; Teller & Palmer, 1996; Franklin & Davies, 2004). Second, recent research indicates that the type of information a feature conveys (i.e., the extent to which it gives rise to object form) is a better predictor of whether that feature will be used to individuate objects than the age at which the feature can be perceived (Woods & Wilcox, 2006).

We have suggested that the developmental hierarchy favoring form features reflects, to a greater extent, information-processing biases (Wilcox, 1999; Wilcox, Schweinle, & Chapa, 2003). According to this hypothesis, when faced with an individuation problem, infants (who have limited information-processing resources) attend to those features that are intimately tied to objects and that are predictive and stable over time. Form features specify the physical nature of objects: the space they occupy, their substance, and how they will move and interact with other objects. Form features are also important for interpreting physical events. For example, the size and shape of an object determines whether it can fit into a container or serve as a source of support for another object. In addition, the form of an object rarely changes or becomes altered, and even young infants expect object form to remain stable across time and situations (Meltzoff & Borton, 1979; Spelke, 1979; Gibson & Walker, 1984; Slater & Morison, 1985; Bahrick, 1987; Granrud, 1987; Slater et al., 1990). In contrast, color information has little predictive value. Although color features typically co-occur with other object properties that are meaningful, color information is not unambiguously linked to objects or relevant to understanding the way in which the physical world operates (e.g., the color of an object does not predict whether it will fit into a container or support another object). In addition, color information is often perceived by infants as unstable across viewing conditions (Dannemiller & Hanko, 1987; Dannemiller, 1989). Because of these factors, infants do not view color information as particularly salient when tracking objects across space and time.

Implicit in this analysis is the idea that if infants could be led to view color as predictive and intimately linked to objects across context, they would be more likely to use color differences to individuate objects. That is, the experience of viewing color information as constant, in a world in which color is typically arbitrary, would lead infants to perceive color information as relevant to object individuation. This conceptual framework forms the foundation for the priming studies we have conducted.

We have used two different approaches to test the hypothesis that infants can be primed to attend to surface features through select experiences. One approach is to make surface features functionally relevant. In these experiments, infants view events in which the color of an object predicts the function in which it will engage. The second approach is to facilitate infants' perception of color as a stable and enduring object property. In these experiments, infants are allowed multisensory (i.e., visual and tactile) exploration of the objects before the test event. These two sets of priming studies are described in the next two sections.

PRIMING SERIES I: MAKING COLOR PREDICTIVE BY PAIRING COLOR WITH OBJECT FUNCTION

In our first set of priming studies, we examined the extent to which pairing color with object function would increase infants' sensitivity to color differences. There is evidence that infants are sensitive to the functional properties of objects and find these properties particularly salient when observing and interacting with objects (Freeman, Lloyd, & Sinha, 1980; Meltzoff, 1988a, 1988b; Pier-LeBonniec, 1995). The fact that infants attend so closely to object function led us to hypothesize that if color were predictive of function, infants would find color differences more salient. That is, priming would be most effective if color were paired with an object property to which infants are already sensitive.

Color–Function Priming

In the first experiment of this series, 9.5-month-olds saw two pairs of pretest events prior to the familiarization and test events; each pair consisted of a pound event and a pour event (Fig. 5–3) (Wilcox & Chapa, 2004). In the first pair of pretest events, a green can with a handle pounded a peg; then a red can with a handle poured salt. The two cans were identical in appearance except for their color. In the second pair of pretest events, the green and red cans were replaced with green and red cups (Fig. 5–4). That is, the first pair of pretest events was seen with Object Pair 1 of Fig. 5–4 and the second pair of pretest events was seen with Object Pair 2 of Fig. 5–4. Following the pretest events, the narrow-screen procedure was employed. In the test event, infants saw a green ball–red ball event with the narrow or the wide screen. Previous research indicates that when viewing this occlusion sequence, infants younger than 11.5 months look equally at the

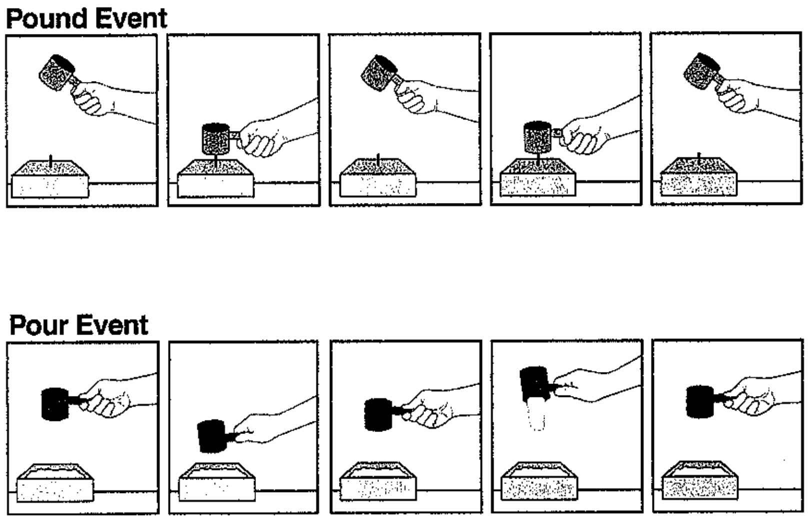


Figure 5–3. The pound–pour events of Wilcox and Chapa (2004). The cup that pounded was green, and the cup that poured was red.

narrow- and the wide-screen test event (Wilcox, 1999; Wilcox et al., 2007 [Experiment 1]). However, after viewing the pound–pour events, the 9.5-month-olds looked reliably longer at the narrow- than at the wide-screen test event, as if they had now used the color difference to individuate the balls. These results suggest that showing the infants the functional value of attending to color information (the only way the infants could distinguish between the two containers and the function they would serve was by their color) heightened infants' sensitivity to color features in the test event.

Additional research revealed two constraints on the effectiveness of this priming procedure (Wilcox & Chapa, 2004). First, the actions in which the objects engage must be functionally relevant. For example, in one experiment, 9.5-month-olds were tested using the same procedure, with one modification: In the pound event, the green containers moved up and down to the right of the peg, without ever coming in contact with the peg; and in the pour event, the red containers made scooping and pouring motions to the right of the box with the salt, without actually scooping or pouring salt. Hence, the pound–pour motion events were identical to the original pound-pour events, except that the actions the objects performed were not functionally relevant. The infants in this experiment looked about equally at the two test events, as if they failed to use the color difference to individuate the objects. Simply seeing the objects perform distinct actions was not sufficient to induce infants to attend to color information. Second, infants need to see at least two pairs of pound–pour events with two different object pairs.

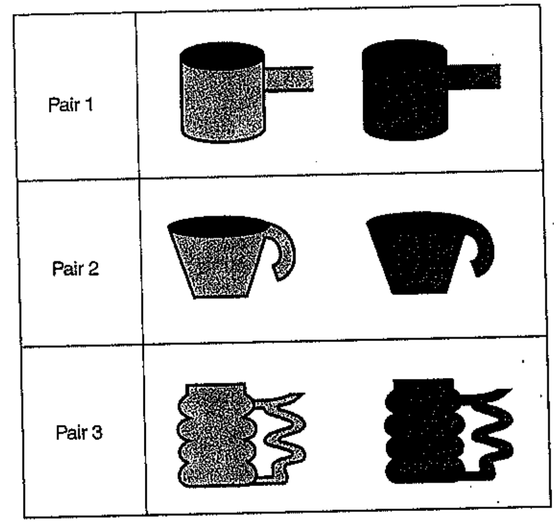


Figure 5–4. The object pairs used in the pound–pour events of Wilcox and Chapa (2004). The cups on the left were green, and the cups on the right were red. Object Pairs 1 and 2 were used with 9.5-month-olds and Object Pairs 1, 2, and 3 were used with 7.5-month-olds.

If 9.5-month-olds see two pairs of pound–pour events with the same object pair (i.e., Object Pair 1 of Fig. 5–4), they do not demonstrate color priming in the individuation task. Similar results are obtained with 7.5-month-olds, except that the younger infants need to see three pairs of pretest trials with three different object pairs (Fig. 5–4). Together, these results suggest that in order for infants to extract the rule that green objects function differently than red objects, they must see multiple pairs of red and green objects (i.e., multiple exemplars). Collectively, these data suggest that it is the formation of categorical event representations in which color is linked to object function that increases infants' sensitivity to color differences.

The Nature of the Representations That Are Formed During Color–Function Priming

In subsequent studies (Wilcox et al., in press), we examined the nature of the representations that are laid down during the priming experience. One issue we have focused on is the level of specificity (or abstraction) at which infants represent feature–function events. For example, in the pound–pour experiments, the infants could have represented the pretest events as (1) green and red objects perform different functions or (2) different-colored objects perform different functions. These make different predictions about the kind of information to which infants will be primed (i.e., green and red only or all colors). To assess these predictions, we tested 9.5-month-olds using a procedure that differed from the pound–pour procedure in two ways. First, the pound–pour events were replaced with stir–lift

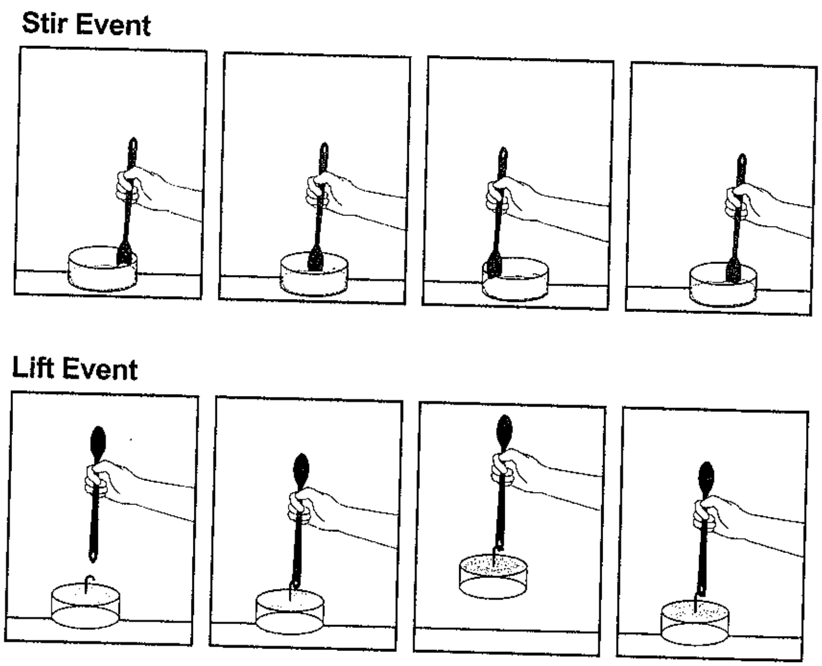


Figure 5–5. The stir–lift events of Wilcox, Woods, and Chapa (in press). The spoon that stirred was green, and the spoon that lifted was red.

events; green spoons stirred salt in a bowl, and red spoons lifted a bowl by a hook (Fig. 5–5). Two pairs of spoons were used (Fig 5–6). Second, the colors of the spoons seen in the stir–lift events were the same as (i.e., green and red) or different from (i.e., yellow and blue) the colors of the balls. If infants are primed to attend only to the color difference seen in the stir–lift event, the infants in the same-colors but not the different-colors condition should successfully individuate the green and red ball. In contrast, if infants are primed to attend to color differences more generally, the infants in both conditions should individuate the green and red balls. The results indicated that the infants in the same-colors condition looked reliably longer at the narrow-screen than at the wide-screen test event. In contrast, the infants in the different-colors condition looked about equally at both test events. The infants were primed to attend only to the color difference seen in the stir–lift events, suggesting that their representation of the events was quite specific.

It is possible, however, that, given the appropriate exemplars, infants would form event representations that were more abstract. There is evidence from the categorization research that when category exemplars are made more variable, infants' categorical representations become more inclusive (Quinn, Eimas, & Rosenkrantz,

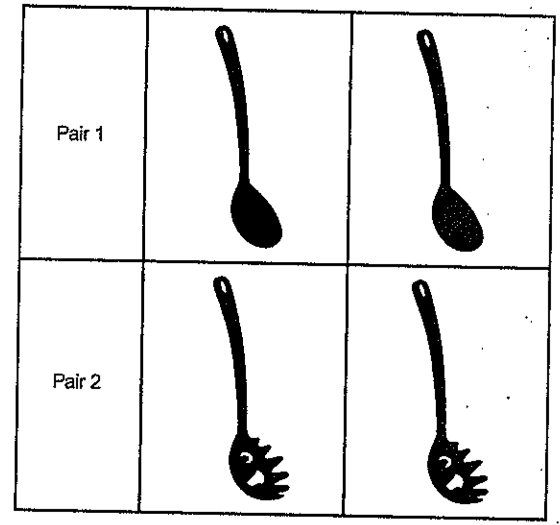


Figure 5–6. The object pairs used in the stir–lift experiments of Wilcox, Woods, and Chapa (in press). In the same-colors condition, the spoons in each pair were green and red. In the different-colors condition, the spoons in each pair were yellow and blue.

1993). Perhaps infants would be more likely to generalize to other colors in the test event if each pair of pretest events (e.g., each exemplar of the relation between color and function) were seen with a different color pair. To assess this possibility, 9.5-month-olds were tested using the stir–lift procedure described above, except the first pair of spoons was yellow and blue, and the second pair was purple and orange (Wilcox et al., in press). To our surprise, the results suggested that "old" 9.5-month-olds (9 months, 13 days to 10 months, 5 days) responded differently to this manipulation than did "young" 9.5-month-olds (8 months, 22 days to 9 months, 12 days). For ease in discussion, we will refer to these two groups as 9.5-month-olds and 9-month-olds, respectively. The 9.5-month-olds looked reliably longer at the narrow-screen than at the wide-screen test event, indicating that they individuated the green and the red ball. In contrast, the 9-month-olds looked about equally at the narrow- and the wide-screen test events, indicating that they failed to use the difference in color to individuate the balls. These results suggest two conclusions. First, after viewing events in which different-colored objects performed different functions, the 9.5-month-olds extracted from the experience that color differences, more generally, are important. Hence, they attend to other, novel colors in the test events. Second, there is an important change during the ninth month of life in infants' capacity to form event categories that are more inclusive. Whereas the 9.5-month-olds successfully formed event categories that generalized across color, the 9-month-olds failed to do so.

Finally, we investigated the extent to which we could facilitate the younger infants' formation of event categories that were more inclusive (Wilcox et al., in press). The goal of these studies was to identify the underlying basis for nine-month-olds' difficulty in forming inclusive event categories. Two different approaches were used. One approach was to show 9-month-olds the yellow and blue spoons together in the pretest events. Again, drawing from the categorization research, there is evidence that infants 3 to 18 months in age are more likely to demonstrate enhanced performance on categorization tasks when they are allowed to directly compare items than they do when they are presented with items one at a time (Quinn, 1987; Namy, Smith, & Gershkoff-Stowe, 1997; Needham, 2001, Needham, Dueker, & Lockhead, 2005; Oakes & Ribar, 2005). Gentner and Namy (1999) argued that the process of comparison facilitates the extraction of deeper and more abstract relations among category members. On the basis of these findings, we tested nine-month-olds using the stir–lift procedure with the yellow or blue and the purple or orange spoons, with one difference. During the pretest trials, both spoons were visible. When the yellow spoon stirred salt, the blue spoon sat, propped up and in full view, next to the bowl. Similarly, when the blue spoon lifted the bowl, the yellow spoon sat, propped up, next to the bowl being lifted. In this experiment, the nine-month-olds successfully individuated the objects in the green ball–red ball test event, suggesting that direct comparison of the two spoons (i.e., exemplars) in each pair of pretest events facilitated infants' capacity to form a more abstract representation of the stir–lift events.

Another approach we used to facilitate the younger infants' formation of categories that were more inclusive was to show them more exemplars. Previous studies have revealed that presenting infants with more exemplars can sometimes improve color–function priming. For example, in the pound–pour experiments of Wilcox and Chapa (2004), 9.5-month-olds were successfully primed after viewing two pairs of pound–pour events, whereas 7.5-month-olds needed to see three pairs of pound–pour events. Perhaps the nine-month-olds in the stir–lift experiments would be more likely to extract the rule that color is predictive if they were shown an additional set of colored spoons. To assess this hypothesis, another group of nine-month-olds were tested using the stir–lift procedure, except that they were presented with an additional pair of stir–lift events with an additional set of spoons; a brown spoon lifted, and a cream spoon stirred. In contrast to the direct-comparison manipulation, this manipulation did not lead to their looking at the narrow-screen test event for significantly longer than at the wide-screen test event. Seeing an additional exemplar pair did not help the nine-month-olds form a more inclusive event category.

What do these two sets of findings reveal about why 9-month-olds are more limited than 9.5-month-olds in their capacity to form inclusive event categories? One interpretation of these results is that nine-month-olds have difficulty forming event categories that link object color to object function because, as the pretest events unfolded before them, they are unable to keep track of which spoon did what. Infants may be unable to identify, for example, whether the current spoon differs in color from the previous spoon, whether the previous spoon stirred or lifted, or which exemplars "go together" to form a pair. Without a clear representation of the structure of each event, and how the events are related, infants are unable to form a categorical representation of the stir–lift events. When the relation between the exemplars is made more obvious by showing infants the exemplars together during the pretest events, infants demonstrate increased sensitivity

to color differences. In contrast, when infants are shown additional exemplars but are not allowed to directly compare the exemplars in each pair, increased sensitivity to color information is not observed. For younger infants, it is not sufficient to simply see more exemplar pairs in the pretest events; the relation between the exemplars in the stir–lift events must be made transparent before infants are able to form color–function categories that support individuation by color.

Related Priming Work

The positive results obtained in the color–function experiments raise the question of whether infants can be primed to attend to other surface features. For example, it is not until 7.5 months that infants spontaneously use pattern differences to individuate objects (Wilcox, 1999). Can younger infants be primed to attend to pattern information? Using the pound–pour procedure, we have assessed the extent to which 5.5- and 4.5-month-olds can be primed to individuate objects on the basis of pattern differences (Wilcox & Chapa, 2004). In these studies, infants saw pound–pour pretest events in which dotted containers pounded the peg, and striped containers poured salt. The pound–pour pretest events were followed by a dotted ball–striped ball test event. Both the 4.5- and the 5.5-month-olds demonstrated pattern priming: After viewing the pound–pour events, they used the difference in pattern to individuate the dotted and the striped ball. However, in order for the 4.5-month-olds to successfully form a categorical representation of the pound–pour events and then attend to pattern differences in the test event, they needed to see the containers presented simultaneously in the pretest events. For example, in the pound event, while the dotted container pounded the nail, the striped container sat close by in the display. Likewise, in the pour event, while the striped container poured salt, the dotted container sat close by. These results mirror those obtained with the nine-month-olds in the different-colors experiment: In order to generalize across multiple color pairs in the stir–lift pretest events, nine-month-olds needed to see the exemplars (i.e., the spoons in each pair) together. These results also provide converging evidence for the conclusion that direct comparison of exemplars is highly effective in facilitating in infants the formation of categories that are more inclusive.

Finally, it should be noted that other researchers have also reported, in other physical domains, that infants can be led, through select experiences, to attend to information to which they typically do not attend (Wang & Baillargeon, 2005). For example, there is evidence that, by 3.5 months, infants attend to height information when interpreting occlusion events (Baillargeon & Graber, 1987; Baillargeon & DeVos, 1991). In contrast, it is not until about 12 months that infants attend to height when interpreting uncovering events (Wang, Baillargeon, & Paterson, 2005). Wang and Baillargeon (2005) examined whether infants could be led to attend to height in an uncovering event if the object involved was first seen in an occlusion event. The results revealed that viewing an event in which height has already been identified as a relevant variable (i.e., an occlusion event) can lead infants to attend to height information in an event in which they typically do not attend to height information (i.e., an uncovering event). These findings provide converging evidence for the idea that infants' object representations are flexible and can be altered by recent experiences.

Summary

The outcome of the color–function experiments reported here reveals a great deal about the structure of the infant mind and how early representations are influenced by recent experiences. First, the color–function results illustrate just how hard infants work to make sense of the world. When observing physical events, infants identify relevant relationships between different types of information and use these relationships to build object and event categories. At the same time, infants do not attend to any and all associations or regularities. The actions the objects perform must be functionally relevant in order for color priming to be supported. We suspect that color–function pairings worked—infants built categories that included this information—because infants perceive object function as a pervasive, meaningful, and salient object property. Apparently, infants use information that is already meaningful to them to identify new sources of information as relevant to the individuation problem. We also suspect that there are other object properties (e.g., the mechanical or causal properties of objects) that infants perceive as useful and meaningful that will support color priming. For example, it is possible that viewing color–mechanics pairings (i.e., objects that are green are self-propelled, and those that are red are inert) would prime infants to attend to color differences.

Second, the nature of the event categories that infants form depends on the exemplars seen. For example, when the exemplars (i.e., pairs of spoons) were all of the same color pair (i.e., yellow and blue), infants' event categories were relatively specific: Infants failed to generalize to the green and red balls in the test trials. However, when the exemplar pairs were more variable (infants saw a pair of yellow and blue spoons and a pair of orange and purple spoons), 9.5-month-olds successfully generalized to the green and red balls in the test events. Nine-month-olds were also able to generalize across color, but only when they were allowed to directly compare the exemplars during the pretest events. Although unpredicted, these results point to an important transition during the ninth month in infants' capacity to form event categories that are more inclusive.

Third, the formation of event categories, which occurs quickly and with relatively few exemplars, has unprecedented effects on object processing. The fact that infants organize objects and events into categories is a well-documented finding (for reviews, see Quinn & Eimas, 1996; Mandler, 1997; Baillargeon, 1998; Madole & Oakes, 1999). The color–function priming results are unique in demonstrating that the formation of event categories can influence how infants perceive and think about objects in subsequent and unrelated events. Infants' propensity to form categorical representations of physical events is a powerful tool. It allows infants to organize physical events as they unfold before them, aids in their interpretation of those events, and biases how they interpret future events.[2]

Finally, the present results point to a flexibility in the type of information that infants include in their object representations. Although infants may not spontaneously attend to color differences in occlusion events, they can be led to do so if color information is made functionally relevant. Hence, sensitivities are dependent, at least to some extent, on the situation and infants' recent experiences.

PRIMING SERIES II: LINKING COLOR TO OBJECTS THROUGH VISUAL AND TACTILE EXPLORATION

The second approach we have taken to color priming is quite different from that of the color–function experiments. The rationale behind this approach is that if we can lead infants to believe that color features are intimately tied to objects, and remain stable over time and situations, infants will be more likely to use color differences as the basis for individuating objects.

What kinds of experiences might lead infants to link color to objects such that they will include color information in their object representations? Once infants can sit up unsupported and begin to reach for and actively manipulate objects, around five months of age (Rochat, 1989; Streri, 1991/1993; Rochat & Goubet, 1995), simultaneous visual and tactile exploration is one of the most common mechanisms for learning about objects. Visual and tactile exploration provides infants with the opportunity to experience the same information in more than one modality (e.g., shape encoded tactilely and visually) and to link information from one modality to another (e.g., link the color of an object to its shape). In other words, the redundancy in information that multimodal experiences affords increases the likelihood that amodal features will be encoded. It also provides a structure with which to integrate modality-specific information. Together, these experiences lead to the formation of multimodal object representations that are richer and more robust than unimodal representations (Slater, Quinn, Brown, & Hayes, 1999; Hernandez-Reif & Bahrick, 2001; Bahrick & Lickliter, 2002; Bahrick, Flom, & Lickliter, 2004). Hernandez-Reif and Bahrick (2001) reported that six-month-olds were more likely to include color and pattern in their representation of an object and to later recognize that object based on its color and pattern information if they were allowed to explore the object in two modalities simultaneously.

Together, these findings led us to hypothesize that infants might be more likely to include color in their object representations and then use color to individuate objects if they were allowed multisensory exploration of the objects before test trials. To test this hypothesis, we examined the extent to which simultaneous visual and tactile exploration of objects increases infants' sensitivity to color information in a subsequent individuation task.

Color Priming Through Multisensory Exploration

In the first of a series of experiments, 10.5-month-olds were assigned to one of two conditions: multisensory exploration or unisensory exploration (Wilcox et al., 2007). In the multisensory exploration condition (Fig. 5–7), infants were presented with two pre-exposure trials before the familiarization and test events. In the first pre-exposure trial, infants were allowed to look at and touch the green ball for

Figure 5–7. An infant being handed a ball and engaging in multisensory exploration. Infants were presented with a green ball on the first pre-exposure trial and a red ball on the second pre-exposure trial.

60 seconds. In the second pre-exposure trial, the same procedure was used with the red ball. The balls were presented successively, never together, and the pre-exposure trials were conducted in a room different from that of the test trials. Following the pre-exposure trials, infants were escorted to the testing room where the narrow-screen procedure was employed. In the test trials, they saw the green ball–red ball event with the narrow or the wide screen. In the unisensory exploration condition, infants were tested using the same procedure, with one important difference: Infants were allowed to look at but not touch the balls during the pre-exposure trials. The results indicated that the infants in the multisensory exploration condition looked reliably longer at the narrow- than at the wide-screen test event, whereas the infants in the visual exploration condition looked about equally at the two test events. Combined visual and tactile exploration of the objects, but not visual exploration alone, increased infants' sensitivity to color information in the test trials.

One interpretation of these results, and the one we would like to offer, is that simultaneous visual and tactile exploration led the infants to form multimodal representations of the balls, which included color information. Once color

information was integrated into their object representations, infants drew on this information to individuate the balls. However, there is an alternative, weaker interpretation of the data. It is possible that two manual presentations of the ball led the infants to conclude that two physically distinct balls were present. That is, the experience of tactilely encountering the balls on two separate occasions (i.e., two trials) was sufficient to signal the presence of two objects. According to this interpretation, it was the number of times the balls were manually presented to the infants, and not color information, that led the infants to individuate the balls.

To assess this interpretation, another group of 10.5-month-olds was tested using the multisensory exploration procedure described above, with one important difference: The infants were presented with the same ball on both pre-exposure trials. Half of the infants were presented with the green ball twice, and the other half were presented with the red ball twice. Following the multisensory exploration control procedure, infants saw the narrow-screen green ball–red ball test event.

The data obtained with the infants in the multisensory exploration control condition, who saw only the narrow-screen event, were compared to the data obtained with the infants in the multisensory exploration condition (narrow-screen event), who individuated the balls, and the infants in the unisensory exploration condition (narrow-screen event), who failed to individuate the balls. The results revealed that the looking times of the infants in the multisensory exploration control condition differed reliably from those of the infants in the multisensory exploration condition but not from those of the infants in the unisensory exploration condition. The infants in the multisensory exploration control condition, like the infants in the unisensory exploration condition, failed to individuate the green and the red ball. These results suggest that the multisensory exploration procedure facilitates infants' performance on the individuation task because it increases their sensitivity to color information and not because two manual presentations signal two distinct objects.

Additional Multisensory Priming Results

In a subsequent experiment, we assessed whether visual exploration would be sufficient to support color priming, (i.e., lead to increased sensitivity to color information) under more supportive conditions. Perhaps if infants, on each pre-exposure trial, were simultaneously shown the green ball and the red ball, they would be more likely to use color information as the basis for individuating objects. That is, if the task of establishing distinct object representations was made easier for the infants, by giving them clear spatiotemporal information about the number of balls present in the pre-exposure trials, infants would find it easier to integrate color into their object representations.

To assess this hypothesis, 10.5-month-olds were tested in one of two conditions that were similar to the multisensory exploration and unisensory exploration conditions described above, with one important difference: In the pre-exposure trials, the green ball and the red ball were presented together, side by side. Hence, infants were given clear spatiotemporal information that two objects—a green ball and a red ball—were present in the pre-exposure trials.

The results indicated that the infants in the multisensory, but not the unisensory, exploration condition looked reliably longer at the narrow- than at the wide-screen test event. That is, only the infants in the multisensory exploration condition individuated the balls in the test event. These results have two important implications. First, they suggest that infants do not simply transfer information about number of objects seen in the pre-exposure trials to the test trials. In both conditions, infants saw two spatiotemporally distinct objects in the pre-exposure trials. Yet the infants in the unisensory exploration condition did not interpret the test event as involving two objects. Second, these data provide converging evidence for the conclusion that combined visual and tactile exploration is critical to color priming in this situation. Even when spatiotemporal information signals the presence of two distinct objects—a green ball and a red ball—infants do not integrate color information into their object representations unless they are allowed simultaneous tactile and visual exploration of the balls.

At first glance, these results may appear in conflict with other data that suggest that spatiotemporal information is fundamental to the individuation process. For example, if infants are given clear spatiotemporal information, in the apparatus and immediately before the test event, about the number of objects present (e.g., infants are shown two objects simultaneously), they use that information as the basis for individuating objects (Spelke, et al., 1995; Xu & Carey, 1996; Aguiar & Baillargeon, 2002; Wilcox & Schweinle, 2003). Why does spatiotemporal information presented during the pre-exposure trials fail to facilitate performance in the test trials? We would argue that during the pre-exposure experience infants form representations of the objects that either include, or do not include, information about the color of those objects. Infants include color information when they are allowed multisensory exploration of the objects but not when they are allowed unisensory exploration. When infants' representations of the balls do not include color information, so that there is no way to determine whether the balls seen to each side of the screen in the test trials are distinct, infants are unable to complete the individuation process. Hence, infants do not simply assume that because two objects were seen in the pre-exposure trials that two objects are involved in the test event. Interpretation of the test event depends on infants' capacity to integrate color information into their object representations in the pre-exposure trials.

The Development of Multisensory Priming

The positive results obtained in the multisensory conditions led us to question whether multisensory priming could be obtained in younger infants. To address this question, 9.5-month-olds were tested using the multisensory exploration, different-context procedure. To our surprise, the results were negative: The 9.5-month-olds looked about equally at the narrow- and the wide-screen test event. Unlike the 10.5-month-olds, who benefited from multisensory exploration, the 9.5-month-olds' sensitivity to color information was not altered by combined visual and tactile exploration of the balls. Why does multisensory exploration facilitate color priming in 10.5-month-olds but not in 9.5-month-olds? There are at least two possible explanations for this pattern of results. One possibility is

that 9.5- and 10.5-month-olds engage in different types of behaviors during the pre-exposure trials, some of which are more likely to support multisensory priming than are others. For example, perhaps 10.5-month-olds spend more time interacting with the objects or being in combined visual and tactile contact with the objects than 9.5-month-olds do. Alternatively, the exploration behaviors of 9.5- and 10.5-month-olds during the pre-exposure trials do not differ reliably, but 9.5-month-olds process and use the information acquired through multisensory experiences in a different way, a way that does not support color priming.

As a first step toward assessing these two possible interpretations, we have investigated the extent to which 9.5- and 10.5-month-olds engage in different types of exploratory behaviors during the pre-exposure trials. In an initial experiment, we coded the visual and tactile behaviors of 9.5- and 10.5-month-old infants during multisensory exploration of the objects (Wilcox et al., 2005). The behaviors we assessed included the amount of time infants spent acting on the object (e.g., tapping, scratching, rubbing, grasping, mouthing, banging, rolling), the amount of time infants spent in combined visual and tactile exploration of the ball (i.e., were touching and looking at the object simultaneously), and the amount of time infants spent in contact with the ball with one hand or both hands together. The results suggested that although the age groups varied in their tendency to use one or two hands in their exploration of the balls (the 9.5-month-olds were more likely than the 10.5-month-olds to engage in two-handed exploration), they did not vary reliably in the overall amount of time they spent tactilely exploring the ball or in the amount of time they spent in combined visual and tactile exploration. We believe, however, that these negative findings need to be interpreted with caution. For example, it is possible that there are subtle age differences in exploratory behaviors that were not captured in this initial study. Perhaps analysis of more specific behaviors (e.g., rolling or tapping the ball) with larger sample sizes would bring these subtle differences to light. In addition, the fact that the age groups did not differ significantly in the type of exploratory behaviors in which they engaged does not necessarily mean that exploratory behaviors are not correlated with individuation performance. It is possible that individual differences in the way in which infants interact with objects better predict individuation performance than does age group.

Of course, it is possible that subsequent research will fail to identify a direct relationship between exploratory behaviors and individuation performance. If we find that 9.5- and 10.5-month-olds do not differ in the type of exploratory behaviors in which they engage, and that exploratory behaviors do not predict individuation performance, then we must consider the alternative hypothesis: 9.5- and 10.5-month-olds do not acquire and use information gained through similar behavioral interactions in the same way. This is a more complicated problem that will require creative methods of study.

Summary

The outcomes of the multisensory priming experiments indicate that combined visual and tactile exploration of objects prior to an individuation task can lead to increased sensitivity to color information in 10.5-month-olds. Unisensory exploration does not have the same effect: Visual exploration alone does not prime infants to attend to color differences in the individuation task. We have proposed that combined visual and tactile exploration of objects leads to the formation of object representations that are richer and more robust and more likely to include color information. That is, multisensory exploration provides infants with the opportunity to form representational structures with which color information can be integrated.

Perhaps the most striking aspect of these results is that a very simple manipulation—allowing infants to look at and touch the balls at the same time—can lead infants to attend to color differences. This everyday experience in which infants frequently engage can have profound effects on the type of information infants include in their object representations. At the same time, we have much to learn about the relation between infants' exploratory behaviors and the kind of information to which they attend and that they represent. For example, we have yet to identify whether it is the type of behaviors in which infants engage or the way in which they process and use the information they glean that predicts performance on an individuation task. This area is ripe for investigation, and the outcomes of future studies have the potential to enhance our understanding of the mechanisms that underlie developmental changes in infants' representational capacities.

Finally, the multisensory priming experiments revealed an intriguing developmental progression in the extent to which infants benefit from visual and tactile exploration of objects. In contrast to the positive results obtained with the 10.5-month-olds, the results of studies with the 9.5-month-olds showed that the younger group did not demonstrate increased sensitivity to color differences after multisensory exploration of the objects. The charge of future research will be to identify the underlying basis for this age-related difference in color priming.

CONCLUSIONS

In our priming studies, we have identified two different mechanisms by which we can increase infants' sensitivity to color information in an individuation task: color–function priming and multisensory priming. The outcome of these studies has shed light on the development of object individuation by showing how select experiences can influence the kind of information infants include in their object representations and by revealing the ways that infants begin to identify new sources of information as important to the individuation problem.

The findings obtained in the color–function priming experiments suggest that one way to increase infants' sensitivity to color information is to make color differences predictive of object properties that infants already find salient (e.g., function). By attending to the relation between color and an already salient object property, infants come to recognize that color, a property they typically find of little value, may in fact be relevant. They then bring this information to bear in a subsequent individuation task. However, there are some interesting limitations to

the extent to which this priming mechanism is effective. First, some object properties are more meaningful and salient than others and hence are more effective as a prime. Second, the capacity to form event categories that link one object property to another constrains the priming processes.

The findings obtained in the multisensory priming experiments reveal a very different way that infants can be led to attend to color information: through simultaneous visual and tactile exploration of the objects. Combined visual and tactile exploration, prior to the individuation task, provides infants with the opportunity to form multimodal representations of the objects. These multimodal representations are more likely than unimodal representations to include color information and, hence, are more likely to support individuation by color. At the same time, there is much to learn about multisensory priming. For example, compared to what we know about color–function priming, we know little about the nature of the representations that are laid down during the multisensory priming experience. Are the representations formed during multisensory experiences specific or abstract? If infants were shown different objects (e.g., a green truck and a red truck) or different color pairs (e.g., yellow and blue balls, and purple and orange balls) during the pre-exposure trials, would they still demonstrate sensitivity to the color difference in the green ball–red ball test event? Investigations of this sort would allow us to identify similarities between the kinds of representations (e.g., specific or abstract) laid down during color–function and multisensory priming.

Finally, we have yet to determine whether the priming effects we have identified with either procedure are transient or long-term. Do these experiences "teach" infants that color is important to object individuation, leading infants to attend to color differences on a regular basis? Or is infants' sensitivity to color differences increased in the short term only? The charge of future research will be to identify the impact that color–function and multisensory experiences have on infants' sensitivity to color (and pattern) information across time and other situations.

In conclusion, the priming studies offer insight into the development of infants' use of features to individuate objects. Of primary importance is that infants can be led to attend to new object properties through select experiences with objects. Future research will address the constraints and limitations of the priming mechanisms we have identified and seek to identify other experiences that will enhance infants' ability to individuate objects. We are confident that further investigation using these and similar procedures will continue to reveal important information about the structure of early object knowledge, the types of experience that can alter this knowledge, and the mechanisms by which this occurs.

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Notes

1. In the narrow-screen violation-of-expectation task, the objects typically move back and forth behind the screen, rather than follow a single trajectory across the platform. To assess whether multiple emergences of the objects are more likely to give rise to the perception of a single object, particularly when a narrow screen is employed, an additional group of infants (*M* age = 6 months, 4 days) were tested using the narrow-screen ball–ball procedure with one difference: The objects reversed direction twice, to travel three lengths of the platform. Again, the infants spent significantly more time reaching to the screen than to the ball; 11 of the 13 infants tested (85%) demonstrated this pattern of reaching. Infants interpret the ball–ball event as involving two objects regardless of whether the objects follow a single trajectory or emerge multiple times from behind the screen.

2. It is important to clarify the distinction between the categorical event representations we have been discussing and the kind of event categorization that Baillargeon and her colleagues have proposed (e.g., Baillargeon, 1998; Baillargeon & Wang, 2002). The former includes local categories that are created "on the fly," that are used in select situations, and that are probably transient. The latter refers to global categories (e.g., occlusion, containment, support) that are deeply embedded in infants' physical knowledge, are used continuously, and remain stable over time.

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We dedicate this book to Sophia, Abbey, and J.D.,
who helped us see the power of young minds.