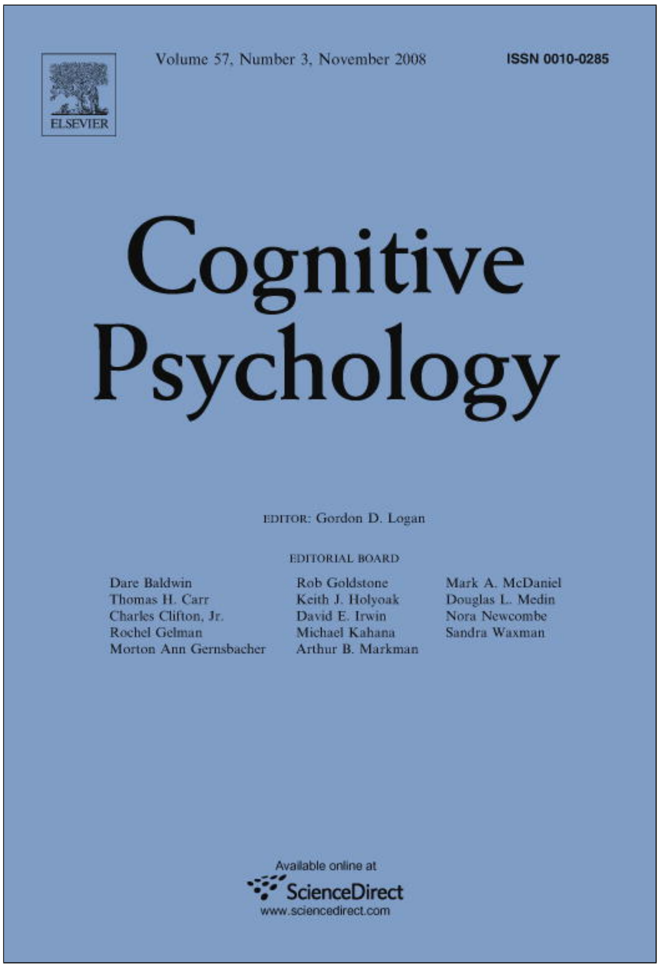
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Color–function categories that prime infants to use color information in an object individuation task

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Abstract

There is evidence for developmental hierarchies in the type of information to which infants attend when reasoning about objects. Investigators have questioned the origin of these hierarchies and how infants come to identify new sources of information when reasoning about objects. The goal of the present experiments was to shed light on this debate by identifying conditions under which infants' sensitivity to color information, which is slow to emerge, could be enhanced in an object individuation task. The outcome of Experiment 1 confirmed and extended previous reports that 9.5-month-olds can be primed, through exposure to events in which the color of an object predicts its function, to attend to color differences in a subsequent individuation task. The outcomes of Experiments 2–4 revealed age-related changes in the nature of the representations that support color priming. This is exemplified by three main findings. First, the representations that are formed during the color–function events are relatively specific. That is, infants are primed to use the color difference seen in the color–function events to individuate objects in the test events, but not other color differences. Second, 9.5-month-olds can be led to form more abstract event representations, and then generalize to other colors in the test events if they are shown multiple pairs of colors in the color–function events. Third, slightly younger 9-month-olds also can be led to form more inclusive categories with multiple color pairs, but only when they are allowed to directly compare the exemplars in each color pair during the present events. These results shed light on the development of categorization abilities, cognitive mechanisms that support color–function priming, and the kinds of experiences that can increase infants' sensitivity to color information.

Keywords: Object individuation; Categorization; Color; Infants; Object function; Object knowledge

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1. Introduction

The visual world is complex and ever changing as objects move about, often disappearing and reappearing as their positions shift in relation to other objects and surfaces. Adults possess sophisticated object knowledge that allows them to interpret and make sense of physical events involving objects. Cognitive scientists have long puzzled over where this knowledge comes from and the way in which early object knowledge gives rise to more sophisticated reasoning. Research conducted over the last 25 years has revealed that some knowledge about objects is present very early in development. For example, from the first months of life infants' segregate the visual world into distinct objects, typically relying on areas of high contrast and motion-related information to parse objects from other surfaces (Kellman & Spelke, 1983; Slater et al., 1990; Slater, Morison, Town, & Rose, 1985; Spelke, 1990). Soon after, infants track the identity of objects as they move about in the world, even when visual contact is lost and spatiotemporal continuity disrupted (Aguiar & Baillargeon, 2002; Spelke, Kestenbaum, Simons, & Wein, 1995; Wilcox & Schweinle, 2003). At the same time, object knowledge changes appreciably during the first year. For example, with time and experience infants identify new sources of information for segregating and individuating objects and become more sophisticated in the type of information they include in their representations of objects and physical events (Baillargeon, 1998, 2004; Needham & Ormsbee, 2003; Wilcox, Schweinle, & Chapa, 2003; Woods & Wilcox, 2006a; Xu, 2002).

More recently, cognitive scientists have turned their attention towards identifying how changes in infants' representational capacities come about. One approach has been to identify experiences that can alter the type of information to which infants attend when interpreting physical events (Baillargeon, 2004; Needham, 2000; Needham, Barrett, & Peterman, 2002; Wang & Baillargeon, 2005; Wilcox & Chapa, 2004; Wilcox, Woods, Chapa, & McCurry, 2007). For example, Needham (2000) documented manipulatory experiences that facilitate object segregation in 3.5-month-olds; Wang and Baillargeon (2005) identified experiences that facilitate 8-month-olds' use of height information when interpreting uncovering events; and Wilcox and her colleagues (Wilcox & Chapa, 2004; Wilcox et al., 2007) reported experiences that increase 4.5–10.5-month-olds' sensitivity to surface features in an object individuation task. Identification of the kinds of experiences that can alter the type of information to which infants attend when forming object representations, and that infants then bring to bear when interpreting events involving those objects, can provide insight into the factors that influence the content of infants' object representations. Furthermore, once we have identified the conditions under which infants integrate new information into their object representations and the conditions under which they transfer this knowledge to other situations, we will be able to identify processes by which learning occurs more generally. The next section describes, in more detail, how this approach has been applied to one component of object knowledge, object individuation, which changes rapidly during the first year of life.

1.1. Object individuation

Object individuation, the capacity to determine whether an object currently in view is the same object or a different object than seen before, is typically assessed within the context of an occlusion situation. In most infant paradigms, participants see an event in which an object moves behind one edge of an occluding screen and, after the object is fully occluded, another object emerges from behind the other edge. When the objects seen to each side of the event are identical in their appearance, and the occlusion interval is appropriate for the object's rate of motion, infants interpret this event as involving a single object that follows a continuous path behind the screen. To identify the type of information that infants bring to bear when tracking objects through occlusion (i.e., that infants use to determine whether the object seen to the right of the screen is numerically distinct from the object seen to left) components of the event are manipulated. For example, to examine the extent to which infants' are sensitive to featural information, the objects seen to opposite sides of the screen are made to differ in their featural properties (e.g., a green ball disappears behind the left edge of the screen and a red box appears at the right edge). Alternatively, to investigate infants' sensitivity to spatiotemporal information a spatiotemporal discontinuity is introduced during the occlusion interval (i.e., the green ball emerges too quickly to have traveled the length of the screen). Looking time or search measures are then used to assess whether infants interpreted the event as involving one or two objects. The collective outcome of these studies indicates that by 3.5 months infants use spatiotemporal discontinuities to individuate objects: infants interpret a discontinuity in path or speed of motion as signaling the presence of two objects. Furthermore, by 4.5 months infants use featural information to individuate objects: when the objects seen to opposite sides of the occluder differ in their featural properties infants use these differences to infer that two objects are present in the event (McCurry, Wilcox, & Woods, 2008; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Schweinle, 2002).

However, there is a developmental hierarchy in the type of featural information to which infants are most sensitive (Wilcox, 1999; Wilcox et al., 2007; Experiment 1; Woods & Wilcox, 2006a). At 4.5 months infants use differences in form features (shape, size), but it is not until much later that infants use differences in surface features (pattern, color, luminance), as the basis for individuating objects. A similar developmental hierarchy has been observed in object segregation and identification tasks (Needham, 1999; Tremoulet, Leslie, & Hall, 2001), suggesting that the advantage for form over surface features prevails across a range of object processing tasks (see also Baldwin, 1989; Booth, 2006; Booth & Waxman, 2002a; Bornstein, 1985a, 1985b). Most relevant to the present research is infants' sensitivity to color information. Infants first demonstrate sensitivity to color differences in an individuation task at 11.5 months (Wilcox, 1999; Wilcox et al., 2007, Experiment 1). This finding is intriguing because by 4 months infants have relatively good color vision: they detect, categorize, and demonstrate memory for color information (Banks & Salapatek, 1981; Banks & Shannon, 1993; Bornstein, 1975; Bornstein, Kessen, & Weiskopf, 1976; Brown, 1990; Catherwood, Crassini, & Freiberg, 1989; Franklin & Davies, 2004; Hayne, Rovee-Collier, & Perris, 1987; Moskowitz-Cook, 1979; Powers, Schneck, & Teller, 1981; Teller & Palmer, 1996). Yet, they fail to use those differences as the basis for individuating objects until the end of the first year.

Wilcox and her colleagues (Wilcox & Chapa, 2004; Wilcox et al., 2007) have argued that the developmental hierarchy observed in object individuation tasks reflects, at least to some extent, infants' experiences in the physical world. Typically, the color of an object is arbitrary and of little predictive value.[1] Although color information may

[1] The present discussion focuses on objects that fall into the category of artifacts. There is evidence to suggest that infants might be more sensitive to color information when identifying objects that belong to other object categories, such as natural kinds (i.e., food items). The importance of object category to infants' sensitivity to color information will be addressed in Section 6.

co-occur with object properties that are meaningful, color information is not unambiguously linked to objects (e.g., color does not typically predict category membership or how an object will be used) or relevant to the understanding of physical events (e.g., the color of an object does not predict whether it will fit into a container or become fully occluded by another object). In addition, because changes in lighting conditions, which occur frequently as objects and light sources change position relative to each other, can alter the percept of color, infants may regard color as unstable across viewing conditions. Indeed, infants are relatively slow to perceive color constancy (Dannemiller, 1989; Dannemiller & Hanko, 1987). Implicit in this analysis is the idea that if infants could be led to view color as predictive, stable, and intimately linked to objects they would be more likely to use color differences as the basis for object individuation. That is, the experience of viewing color information as constant in a world in which object color is typically arbitrary, would lead infants to perceive color information as relevant to the individuation problem.

1.2. Increasing infants' sensitivity to color by making color functionally relevant

How might infants be induced to perceive color as important to reasoning about objects? One approach is to demonstrate the relevance of color by directly linking color to an object property to which infants are already sensitive and find predictive. One property that is deeply embedded in our everyday experiences with objects and that infants (as well as children and adults) find particularly salient when viewing physical events is object function. Function is defined here as an agent produced action on an object that the object affords and/or for which it was intended, either by design or through conventional use (for related definitions see Booth, 2006; Booth & Waxman, 2002a; Casler & Kelemen, 2007; Kemler Nelson, 1995, 1999). Affordances are intimately linked to the structure and the substance of an object and occur naturally or inevitably. For example, a concave rigid surface with a handle affords digging, scooping, holding, and pouring of substances. Although the relation between the structure of an object and its function is often obvious, there are situations in which this is not the case. When the relation is not transparent, knowing the action for which an object was intended (i.e., seeing the object perform the function for which it was designed) is critical to understanding the functional properties of the object. Finally, regardless of whether the relation between objects, object parts, and function is immediately obvious or needs to be demonstrated, this relation contains a causal structure. That is, the features of the object provide a mechanism by which to achieve a goal (i.e., perform the function) and aid the agent in the completion of that goal.

There is evidence that from an early age infants are sensitive to the functional properties of objects. Within the first 6 months of life infants adjust their reaching and hand positions for effective grasping of objects. They recognize affordances of objects and tailor their actions accordingly (Clifton, Rochat, Litovsky, and Perris, 1991; Lockman, Ashmead, and Bushnell, 1984; McCarty, Clifton, Ashmead, Lee, and Goubet, 2001; von Hofsten and Fazel-Zandy, 1984; von Hofsten and Ronnqvist, 1988). In addition, young infants detect the functional relation between object parts and surfaces and use objects in ways that are consistent with these relations (Bourgeois, Khawar, Neal, and Lockman, 2005; Gibson and Walker, 1984; Molina and Jouen, 1998; Palmer, 1989; Ruff, 1984). Infants 8–18 months of age manipulate objects on the basis of the functions they afford (Freeman, Lloyd, & Sinha, 1980; Pieraut-Le Bonniec, 1985), generalize functional properties to objects similar in appearance or that share important characteristics (Baldwin, Markman, & Melartin, 1993; Booth & Waxman, 2002a), and attend to novel ways objects can be used and imitate those actions (Meltzoff, 1988a, 1988b). In addition, older infants and young children use object function as the basis for which to categorize objects, make inferences about the function of an object based on category membership, and extend labels to novel objects that function in a similar way (Booth, 2000, 2006; Booth & Waxman, 2002a; Kemler Nelson, 1995; Kemler Nelson, Frankenfield, Morris, & Blair, 2000; Kemler Nelson, Russell, Duke, & Jones, 2000; Madole & Cohen, 1995). Particularly relevant to the present research is that categorizing objects on the basis of object function can direct infants' attention to other perceptible commonalities among those objects (Booth, 2000). That is, forming functionally relevant categories can lead infants to attend to other perceptual properties that the objects in the category share, such as color, that are not typically linked to the object. Collectively, this body of work suggests that infants are not only sensitive to object function across a wide range of situations and tasks, but that they use function-related information to make inferences about what physical properties an object should possess, how it will be acted on, and the ontological category to which it belongs (the label it should be given). Knowing an objects' function can also facilitate learning new information about the object. What this means is that function is not just a salient object property, it is a means by which infants can draw inferences about novel objects and by which infants can acquire new information about already familiar objects.

On the basis of evidence that infants use function-related information to guide learning about objects Wilcox and Chapa (2004) assessed the extent to which infants' sensitivity to color information could be altered by linking color to object function. In a series of experiments, infants were presented with events, prior to an individuation task, in which the color of an object predicted the function in which it would engage (Wilcox & Chapa, 2004). For example, in one experiment, 9.5-month-olds saw two pairs of pretest events; each pair consisted of a pound event and a pour event (Figs. 1 and 2, Pairs 1 and 2). In the first pair of pretest events, a green can with a handle pounded a peg. Next, a red can with a handle poured salt. The pound and pour events were presented successively and 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. Critical to this experiment is that the colors of the containers were directly and unequivocally linked to their function: the green containers pounded and the red containers poured.

Following the pretest events, infants' capacity to individuate on the basis of color differences was assessed using the narrow-screen task of Wilcox and Baillargeon (1998a, 1998b). In this task, infants see a test event in which featurally distinct objects (e.g., a green ball and a red ball) emerge successively to opposite sides of a screen that is either too narrow (narrow-screen event) or sufficiently wide (wide-screen event) to occlude both objects simultaneously (Fig. 3). If infants use the featural difference to individuate the objects, and recognize that both objects can fit behind the wide but not the narrow screen, they should find the narrow- but not the wide-screen event unexpected. Hence, longer looking to the narrow- than the wide-screen test event is taken as evidence of object individuation. This interpretation of prolonged looking to narrow-screen events

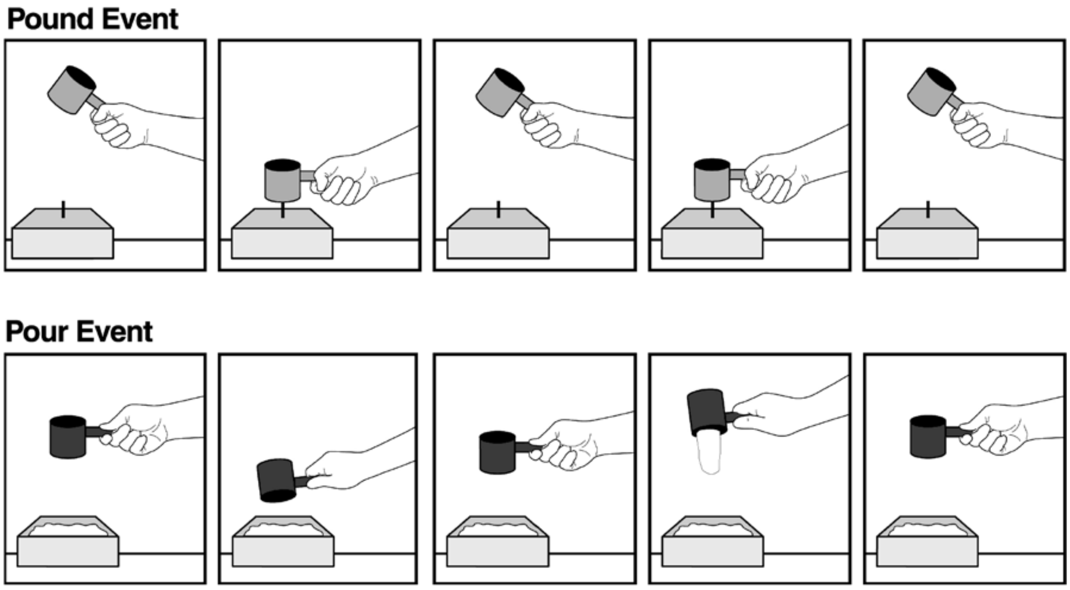

Fig. 1. The pound–pour events of Wilcox and Chapa (2004). The pound event was seen with the green cup and the pour event with the red cup.

is supported by the outcome of other violation-of-expectation (Wilcox & Baillargeon, 1998a; Wilcox & Chapa, 2002; Wilcox & Schweinle, 2002) and search (Wilcox & Woods, in press) tasks.[2]

Previous research using the narrow-screen task indicates that infants younger than 11.5 months look equally at the narrow- and the wide-screen green ball–red ball test event (Wilcox, 1999; Wilcox et al., 2007). That is, they fail to individuate the green and the red ball. However, after viewing the pound–pour events, the 9.5-month-olds in Wilcox and Chapa (2004) looked reliably longer at the narrow- than the wide-screen green ball–red ball 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 color of the container predicted the function in which it would engage—heightened infants' sensitivity to color differences in the test event.

[2] Although some researchers have questioned the extent to which the narrow- screen task assesses object individuation in infants, there is now substantial evidence using different paradigms (McCurry et al., 2008; Wilcox, 1999; Wilcox & Baillargeon, 1998b; Wilcox & Schweinle, 2002; Wilcox & Woods, in press) that infants as young as 4.5 months can use featural information to individuate objects and show prolonged looking to different-features narrow-screen events because they are puzzled to see two objects out of view behind the narrow screen. For example, in a study conducted by McCurry et al. (2008); also reported in (Wilcox & Woods, in press) 5- to-7-month-olds were shown an event in which a box (box–ball event) or a ball (ball–ball event) disappeared behind one edge of a narrow or a wide screen and a ball appeared at the other edge. The screen consisted of a wooden frame to which multiple layers of fringe were attached; infants could reach but not see through the screen. Infants were then allowed to search. The infants who viewed the box–ball event spent significantly more time reaching through the fringed-screen than reaching for the visible ball. In contrast, the infants who viewed the ball–ball event spent more time reaching for the ball than reaching through the screen. Infants in the narrow- and wide-screen conditions performed the same. These results suggest that the infants who saw the box–ball event interpreted the event as involving two objects, one of which was hidden behind the screen at the end of the trial. In addition, even though the narrow-screen box–ball infants may have been puzzled as to how both objects could have been hidden behind the screen, they still perceived the event as involving two objects and actively searched for the box at the end of the event sequence.

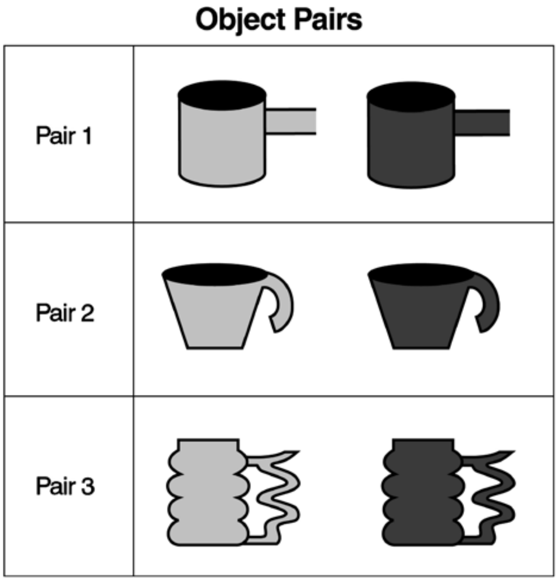

Fig. 2. The object pairs used in the pound–pour events of Wilcox and Chapa (2004). The cups on the left were green and on the right were red. The 9.5-month-olds saw Pairs 1 and 2 and the 7.5-month-olds saw Pairs 1–3.

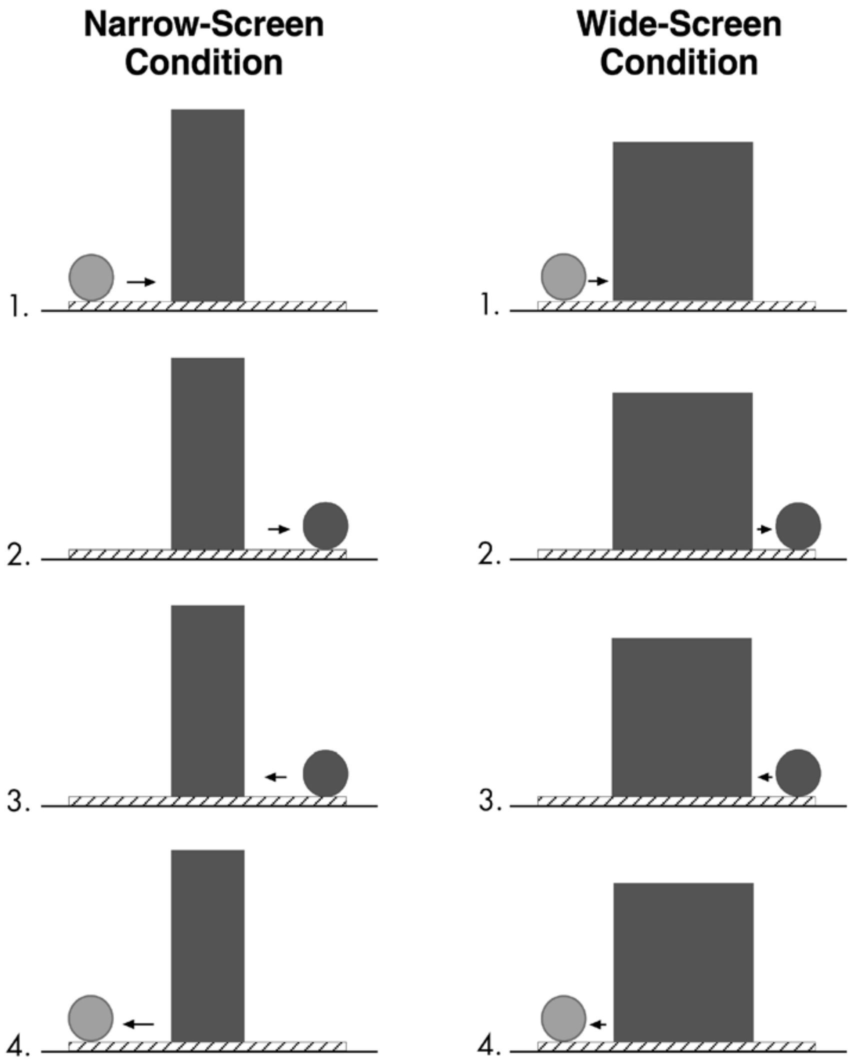

Fig. 3. A schematic of the narrow- and wide-screen test events of Wilcox and Baillargeon (1998a, 1998b). Steps 1–4 repeated until the end of the trial. In Experiments 1–4, the ball on the left was green and on the right was red.

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. If the green and red containers perform distinct actions but these actions do not have an obvious function, color priming is not observed.For example, in one study infants saw pretest events that were identical to the pound–pour pretest events except that the containers did not engage in a function. In the non-function pound event, the green container moved up and down next to the nail, but not did come in contact the nail. In the non-function pour event, the red container titled back and forth over the box, making pouring and scooping motions, without ever coming in contact with the salt. Hence, the main difference between these pound–pour events and the original pound–pour events was whether the actions in which the containers engaged were functionally relevant and not other event characteristics (e.g., the amount of action in which the objects engaged or the complexity of the display). Looking time data suggested that the infants found the two types of pretest events equally interesting: the mean looking times to the non-function and the function pretest events did not differ reliably. Looking time data also revealed that viewing the non-function pretest events did not prime infants to attend to color in the test trials: the infants looked about equally at the narrow- and the wide-screen green ball–red ball test event. These data support the idea that (a) infants distinguish between actions on objects that are functionally relevant and those that are not and (b) weigh these two types of information differently. Furthermore, it is the process of identifying color as relevant to the pretest events—as predictive of object function—that facilitates greater attention to color in the subsequent test event.

These data echo those obtained by Booth (2000) with older infants. Booth reported that when 14-month-olds were familiarized with the functional properties of objects (i.e., saw objects engage in the same function) they were more likely to attend to other features of the objects than when they were familiarized with the non-functional properties of objects (i.e., saw objects engage in an equally dynamic but non-functional activity). That is, knowing the function of an object allowed infants to attend to other, less salient characteristics that similarly-functioning objects shared. According to Booth (2000, 2006), because function is so salient to infants, infants attempt to relate as many characteristics of the object as possible to object function, even when those properties are not directly or causally related to the function.

The second constraint on priming effectiveness has to do with the nature of the exemplars seen. Infants need to see at least two pairs of pound–pour events with two different object pairs. If 9.5-month-olds see two pairs of pound–pour events with the same object pair (Fig. 2, Pair 1) they are not primed to attend to color information 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. 2, Pairs 1–3). If 7.5-month-olds see three pairs of pretest trials but two of those pairs are seen with the same set of containers they are not primed to attend to color information. The key finding is 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 exemplar pairs) performing distinct functions. What this suggests is that infants are not simply forming an association between color and function. If infants were simply associating color with function, then the absolute number of times infants saw color and function linked, and not the number of distinct exemplars of the pairing between color and function, would determine the extent to which color priming occurred. The fact that infants needed to see two (or three) different pairs of pound–pour events with two (or three) different exemplar pairs suggests that categorization processes were involved. That is, priming occurred only when the exemplars were sufficiently diverse to support the formation of object and event categories. This interpretation is consistent with a long-standing finding in cognitive psychology that the categories infants, children, and adults build are highly influenced by the nature of the exemplars seen (Ashby & Ell, 2001; Ashby & Maddox, 2005; Markman & Ross, 2003; Oakes & Ribar, 2005; Quinn, Eimas, & Rosenkrantz, 1993). What is novel about these findings is that they demonstrate that forming object and event categories that include color information—in which color information is linked to object function—can alter infants' sensitivity to color in a subsequent and unrelated task.

1.3. The function of event categories

How are we to understand this unique finding within the context of categorization more generally? In their interactions with objects in the world infants, children, and adults use categories to classify objects, to predict the properties an object might possess, and to learn what distinguishes members of one group from another (e.g., Booth, 2000, 2006; Booth & Waxman, 2002a, 2002b; Casler & Kelemen, 2007; Gelman, Checknick, & Waxman, 2005; Gelman & Coley, 1990; Kemler Nelson et al., 2000; Klibanoff & Waxman, 2000; Markman & Ross, 2003). The outcome of the pound–pour experiments suggest that categorization may have wider ranging effects, at least in infants. More specifically, the process of building object categories in one situation (i.e., pound–pour events), which includes identifying the basis by which to classify items, can influence the type of object information to which infants attend in another situation (i.e., occlusion events). This experience not only supports learning about what distinguishes one type of object from another, it also influences infants' apprehension of objects more generally.

One might be concerned about the extent to which the pound–pour results, which reflect infants' formation of artificially induced categories in an experimental setting, tell us something about the way that categorization processes influence infants' interpretation of new information in the natural environment. There is evidence from a number of laboratories using a wide range of tasks indicating that when infants attempt to make sense of objects and the physical events in which they engage, infants are selective in the type of information to which they attend and use as the basis for building object and event categories (e.g., Baillargeon & Wang, 2002; Booth & Waxman, 2002a; Kemler Nelson, Frankenfield et al., 2000; Wang & Baillargeon, 2005). There is also evidence that once an object or event category has been identified, infants are then able to identify other commonalities among the objects (Booth, 2002, 2006). Heightened sensitivity to these other commonalities, which previously may have been ignored, can influence infants' interpretation of other events closely linked in space and/or time. The fact that similar findings emerge across a range of cognitive tasks suggests that these categorization processes are engaged in a diversity of situations. Hence, we would argue that even though the categories that support color–function priming are artificially induced and specific to this experimental setting, they exemplify more general learning principles that (a) elucidate one way that infants can flexibly and continuously integrate new information into their representations, and (b) transfer this "knowledge" to new situations.

1.4. Present research

Given the relevance of color–function priming to categorization and learning processes more generally we felt compelled to learn more about the mechanisms involved. The purpose of the present research is twofold. The first is to identify the conditions that support the formation of categorical event representations (i.e., the conditions under which infants will successfully link color differences to object function). This will provide insight into how infants go about building object and event categories, and allow us to make more accurate predictions about when color priming will be obtained. The second is to identify the nature of the representations formed during the categorization process. For example, what is the level of specificity (or abstraction) with which infants represent color–function events? There are several ways in which the infants could have represented the pound–pour events. To illustrate, the infants could have represented the events as (1) green and red objects perform different functions or (2) different-colored objects perform different functions. These two interpretations make different predictions about the kind of information to which infants will be primed. The first interpretation predicts that infants will be primed to attend to the color difference seen in the pretest events, and will individuate objects in the test events only if they are of the same color. In contrast, the second interpretation predicts that infants will be primed to attend to color differences more generally, and will individuate objects that differ in color regardless of the color pair seen. Once we have identified the specificity with which infants represent color–function events we will have a better understanding of the kinds of categories that support color–function priming and, more generally, category-based learning.

Infants aged 9.5 months were tested using the pound–pour procedure of Wilcox and Chapa (2004) with two modifications. First, the pound–pour events were replaced with stir–lift events. In the stir event, a spoon stirred salt in a bowl. In the lift event, the bowl was turned upside down and a different-colored spoon lifted the bowl by a hook. Second, the exemplar pairs seen in the pretest events were manipulated. In Experiment 1, the colors of the spoons seen in the pretest events were either the same as (green and red) or different from (yellow and blue) the colors of the balls seen in the test events. The results replicated and extended those of Wilcox and Chapa (2004) by, first, demonstrating that the 9.5-month-olds were primed (in the test event) to attend to the color pair seen in the pretest events and by, second, revealing that this effect did not generalize across color pairs. Viewing green and red spoons, but not yellow and blue spoons, primed infants to individuate the green and red balls (i.e., viewing yellow/blue in the pretest events did not prime infants to attend to green/red in the test events). Experiments 2 through 4 investigated conditions under which infants could be induced to form more inclusive categorical event representations and generalize across color in the pretest and test events. The outcome of these experiments revealed two main findings. First, viewing multiple color pairs in the pretest events (e.g.., a pair of yellow and blue spoons and a pair of purple and orange spoons) led to color priming in 9.5-month-olds. This outcome is consistent with other categorization research indicating that the nature of the exemplars seen influences the type of category formed: the more varied the exemplars the more inclusive the category. Second, younger infants also benefited from viewing multiple color pairs but needed to see the two spoons of each pair together, side-by-side, during the pretest events. This outcome suggests that the younger infants found it easier to detect similarities and differences between the spoons, and to identify the relation between color and function, when they had the oppor-

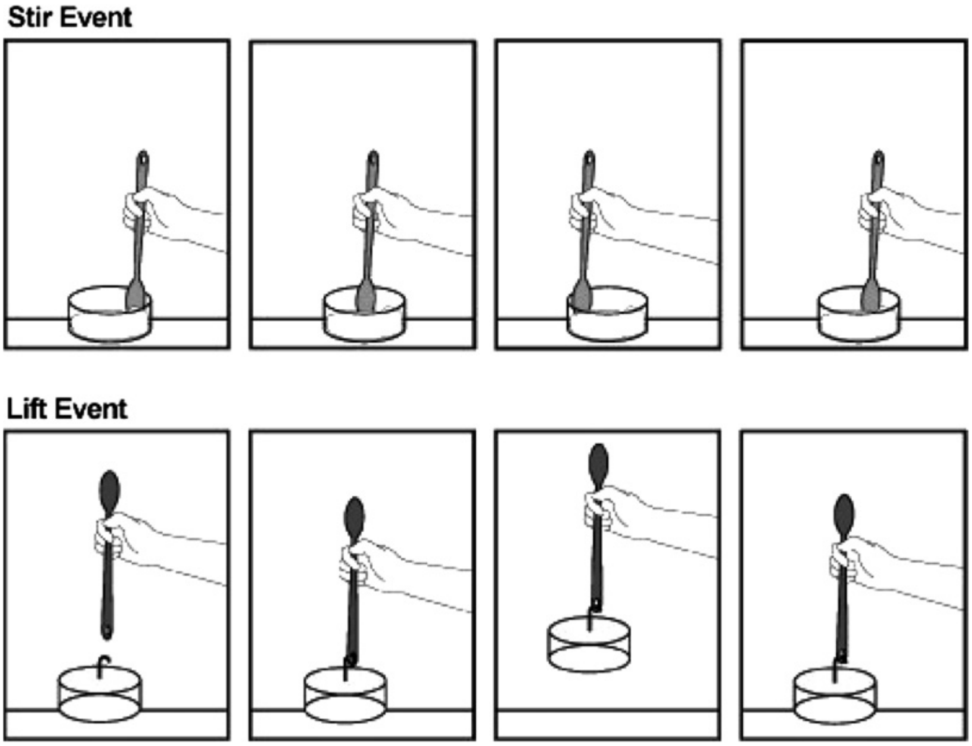

Fig. 4. The stir–lift events of Experiments 1–4. The colors of the spoons varied by experiment and condition.

tunity to directly compare the exemplars during the pretest events. This outcome builds on a growing body of research indicating that direct comparison of exemplars facilitates the formation of more inclusive and abstract categories in infants, children, and adults (e.g., Gentner & Markman, 1994; Gentner & Medina, 1998; Gentner & Namy, 1999, 2004, 2006; Klibanoff & Waxman, 2000). Collectively, the results of these four experiments provide insight into the nature and content of infants' categorical event representations, the cognitive mechanisms that support the formation of more abstract event categories, and the conditions under which transfer of color sensitivity from one situation to another can occur.

2. Experiment 1

Experiment 1 focuses on the level of specificity (or abstraction) at which infants represent color–function events. Recall that in the pound–pour experiments the infants could have represented the pretest events as either (1) green and red objects perform different functions or (2) different-colored objects perform different functions, and that these make different predictions about the kind of information to which infants will be primed (i.e., green and red only or all colors, respectively). To assess these predictions, we presented 9.5-month-olds with stir–lift events (Fig. 4) prior to the test events. The colors of the spoons seen in the stir–lift events were the same as (green and red) or different from (yellow and blue) the colors of the balls (Fig. 5). If infants are primed to attend only to the color difference seen in the stir–lift event, then the infants who see the green and the red spoons, but not the infants who see the yellow and the blue spoons, should successfully individuate the green and the red ball in the test trials. In contrast, if infants are primed to attend to

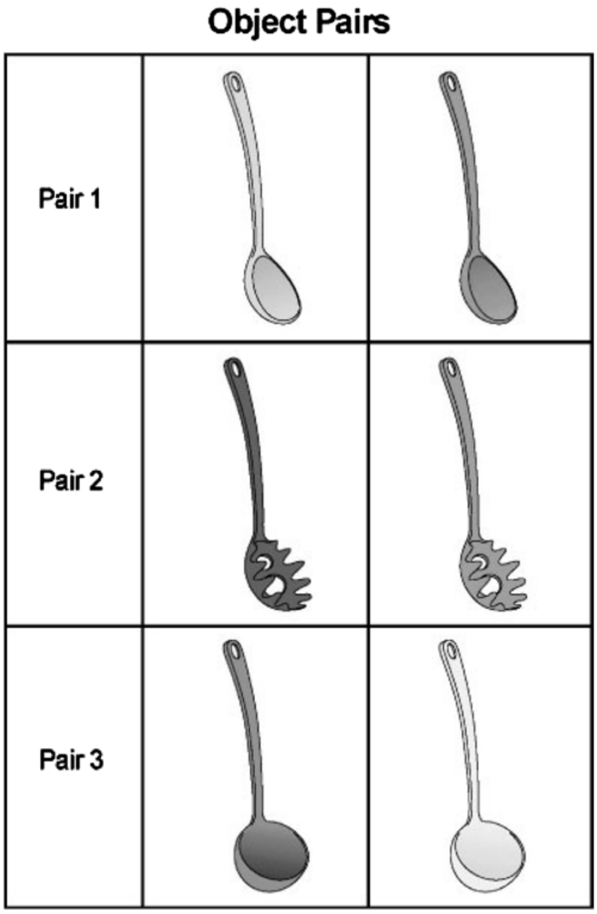

Fig. 5. The object pairs used in the stir–lift events of Experiments 1–3 (Pairs 1 and 2) and Experiment 4 (Pairs 1–3). In Experiment 1, in the same-colors condition the spoons in each pair were green and red and in the different-colors condition the spoons in each pair were yellow and blue. In Experiments 2 and 3, the spoons in Pair 1 were green and red and the spoons in Pair 2 were yellow and blue. In Experiment 4, the spoons in Pairs 1 and 2 were identical to those of Experiment 3 and the spoons in Pair 3 were purple and orange.

color differences, more generally, then the infants in both conditions should individuate the green and the red ball.

2.1. Method

2.1.1. Participants

Participants were 64 healthy full-term infants, 30 male and 34 female (M age = 9 months, 14 days; range = 8 months, 18 days to 9 months, 29 days). Eleven additional infants were tested but eliminated because of failure to attend ($N = 1$), sleepiness ($N = 1$), crying ($N = 2$), procedural difficulties ($N = 3$), family history of colorblindness ($N = 1$)[3], or the primary observer was unable to determine the direction of the infant's gaze ($N = 3$). Sixteen infants were pseudo-randomly assigned (i.e., an attempt was made to balance the number of males and females in each condition) to each of four conditions

[3] In Experiments 1–4, parents were asked to report family history of color blindness. Males were eliminated from the analysis if color blindness was reported for a member of the mother's immediate family. Females were eliminated from the analysis if color blindness was reported for a member of the mother's immediate family and if the biological father was color blind.

formed by crossing spoon color (green and red or yellow and blue) and test event (narrow or wide screen): green and red spoons, narrow-screen (*M* age = 9 months, 16 days; 7 M, 9 F); green and red spoons, wide-screen (*M* age = 9 months, 13 days; 7 M, 9 F); yellow and blue spoons, narrow-screen (*M* age = 9 months, 11 days; 7 M, 9 F); yellow and blue spoons, wide-screen (*M* age = 9 months, 15 days; 9 M, 7 F).

In this and all subsequent experiments, the infants' names were obtained from multiple sources, including birth announcements in the local newspaper and commercially produced lists. Parents were contacted by letters and follow-up phone calls. Parents were offered reimbursement for their travel expenses.

2.1.2. Apparatus and stimuli

The apparatus consisted of a wooden cubicle 213 cm high, 105 cm wide and 43.5 cm deep. The infant sat facing an opening 51 cm high and 93 cm wide in the front wall of the apparatus. The floor and walls of the apparatus were cream or covered with lightly patterned contact paper. A platform 1.5 cm high, 60 cm wide and 19 cm deep lay at the back wall and centered between the left and right walls.

Two types of spoons were used in the pretest events: serving spoons (first pair of pretest events) and slotted spaghetti spoons (second pair of pretest events). Each serving spoon was 31 cm long. The scoop portion was 7 cm wide at the widest point, 10 cm long and 1.5 cm deep. The handle was 2 cm wide, 21 cm long, and.5 cm thick. At the end of each handle was a small hole measuring 1 cm in diameter. The slotted spaghetti spoons were 29.5 cm long. The scoop portion was 6 cm wide at the widest point, 10.5 cm long and 4 cm deep. The handle was 2 cm wide, 21.5 cm long, and.5 cm thick. At the end of each handle was a small hole measuring 1 cm in diameter. The green and the red spoons were painted to match the color and luminance of the green and the red balls used in the test trials (see below). The yellow and the blue spoons were also painted and approximated the hues of the Munsell Matte Collection (Munsell, 2005) yellow 2.5Y 8/10 and blue 7.5PB 2.5/6. The bowls used during the pretest events consisted of clear Rubbermaid® 1.7 Pt bowls measuring 6 cm deep and 14 cm in diameter. The bowl used for the stir event was placed open side up and partially filled with salt. The bowl used for the lift event was placed with the open side down and had a small hook protruding upwards from the center. The hook was 2.5 cm high, 2 cm wide, and.5 cm thick. During the pretest events each bowl sat 2 cm in front of the platform with its right edge 9 cm from the right wall of the apparatus. During the lift event the bowl was placed so that the hook faced the infant.

The balls used in the familiarization and test events were 10.25 cm in diameter and made of Styrofoam®. One ball was painted green and approximated the hue of 2.5G 5/10 of the Munsell Matte Collection (Munsell, 2005). The other ball was painted red and approximated the hue of 5R 4/14 of the same collection. The balls were of equal luminance (35 cd/m^2). Each ball was attached to a clear Plexiglas base and each base had a 16 cm handle that protruded through a small gap between the back wall and floor of the apparatus; the gap was masked by cream-colored fringe. An experimenter, concealed behind the apparatus, could move the balls left and right along the platform using the Plexiglas handle.

The screen used in the familiarization trials was 41 cm high and 30 cm wide and made of yellow cardboard. The narrow test screen was 41 cm high and 17 cm wide and the wide test screen was 33 cm high and 30 cm wide. Hence, the narrow test screen differed from the familiarization screen in width and the wide screen differed from the familiarization screen in height (i.e., each test screen varied from the familiarization screen on one dimension). The test screens were made of blue cardboard and decorated with small gold and silver stars. The screens were mounted on a wooden stand that was centered in front of the platform.

Embedded in the center of the platform was a metal bi-level composed of an upper and a lower shelf 16 cm apart; each shelf was 12.7 cm wide and 13 cm deep. The bi-level was designed so that both objects could be behind the screen simultaneously, one on the top shelf and the other on the bottom shelf. When at rest, the upper shelf was level with the top of the platform and the lower shelf lay underneath the apparatus floor. The bi-level could be lifted by means of a handle 19 cm long that protruded through a vertical opening in the apparatus's back wall; when the bi-level was lifted, its lower shelf became level with the platform. The bi-level remained hidden behind the screen in its raised position.

A muslin-covered shade was lowered in front of the opening in the front wall of the apparatus at the end of each trial. Two muslin-covered wooden frames, each 213 cm high and 68 cm wide, stood at an angle on either side of the apparatus and isolated the infants from the experimental room. In addition to the room lighting, a 20-W fluorescent bulb was affixed to each inside wall of the apparatus.

2.1.3. Events

Each experimental session included pretest, familiarization and test events. One experimenter produced all of the events. The experimenter wore a white glove on her right hand and followed a precise script, using a metronome that ticked softly once per second. The numbers in parentheses indicate the time taken to produce the actions described.

2.1.3.1. Green and red spoons, narrow-screen condition. Each infant saw two pairs of pretest events. Each pair consisted of a stir event and a lift event. At the start of the first stir event, the experimenter held the green serving spoon by its handle, with the open scoop facing the infant and the back of the spoon against the inside of the bowl with the salt. The experimenter stirred the salt by moving the spoon clockwise at a constant rate around the contour of the bowl three times (6 s) and then paused (2 s). The 8-s event sequence was repeated continuously until the end of the trial. In the first lift event, the experimenter held the red serving spoon by its handle, up-side–down, with the open scoop facing the infant. The hole in the handle of the spoon was approximately 7 cm above the bowl with the hook. The experimenter lowered the spoon and hooked it to the bowl (2 s), lifted the spoon and bowl (2 s), lowered the spoon and bowl (2 s), and then unhooked the spoon and raised it to starting position (2 s). The 8-s event sequence was repeated continuously until the end of the trial. The second pair of pretest events was identical to the first except that the slotted green and red spoons were used.

Following the pretest events, the infants saw a familiarization event. At the start of each familiarization trial, the green ball sat with its center 6 cm from the left end of the platform. The familiarization screen stood upright and centered in front of the platform, and the red ball sat on the lower shelf of the bi-level.

Each familiarization trial began with a brief pretrial. When the computer signaled that the infant had looked for 1 cumulative second, the ball paused for 1 more second and then moved to the right until it reached the upper shelf of the bi-level behind the screen (2 s), so that the handle of the ball's base aligned with the handle of the bi-level. Next, the bi-level was lifted until its lower shelf was level with the platform (1 s); the red ball then emerged from behind the screen and moved to the right until its center was 6 cm from the right end of the platform (2 s). After a 1-s pause, the red ball returned to the bi-level (2 s) which was lowered (1 s) until its upper shelf was once again even with the platform; the green ball then returned to its starting position at the left end of the platform (2 s). When in motion the balls moved at a rate of 12 cm per s. The 12-s event sequence just described was repeated continuously until the trial ended.

Next, the infants saw a test event. The test event was identical to the familiarization event except that the yellow familiarization screen was replaced with the narrow blue test screen.

2.1.3.2. Green and red spoons, wide-screen condition. The pretest, familiarization, and test events were identical to those of the narrow-screen condition with one exception: in the test event the narrow blue screen was replaced with the wide blue screen.

2.1.3.3. Yellow and blue spoons, narrow- and wide-screen conditions. The pretest, familiarization, and test events were identical to those of the green and red spoons, narrow- and wide-screen conditions except that the green and red spoons were replaced with the yellow and blue spoons. The green/red and yellow/blue spoon pairs were identical in appearance except for their color.

2.1.4. Procedure

Each infant sat on a parent's lap centered in front of the apparatus, approximately 78 cm from the objects on the platform. Parents were asked not to interact with their infant while the experiment was in progress and to close their eyes during the familiarization and test trials.

The infants participated in a three-phase procedure that consisted of a pretest, familiarization, and test phase. During the pretest phase, the infants saw the four pretest events appropriate for their condition on four successive trials. Each trial ended when the infant (a) looked away for 2 consecutive seconds after having looked at the event for at least 10 cumulative seconds or (b) looked for 30 cumulative seconds without looking away for 2 consecutive seconds. During the familiarization phase, the infants saw the familiarization event appropriate for their condition on six successive trials. Each trial ended when the infant (a) looked away for 2 consecutive seconds after having looked at the event for at least 12 cumulative seconds (beginning after the pretrial) or (b) looked for 60 cumulative seconds without looking away for 2 consecutive seconds. During the test phase, the infants saw the test event appropriate for their condition on two successive trials. Each trial ended when the infant (a) looked away for 2 consecutive seconds after having looked at the event for at least 6 cumulative seconds (beginning after the pretrial) or (b) looked for 60 cumulative seconds without looking away for 2 consecutive seconds. The number of pretest, familiarization, and test trials each infant saw and the trial termination criteria were identical to those used with the 9.5-month-olds in Wilcox and Chapa (2004).

The infant's looking behavior was monitored by two observers who watched the infant through peepholes in the cloth-covered frames on either side of the apparatus. The observers were not told, and could not determine, whether infants saw a narrow- or a wide-screen test event[4]. Observers held a button connected to a computer and depressed the button when the infant attended to the events. The looking times recorded by the primary observer determined when a trial had ended and were used in the data analyses. Each trial was divided into 100-ms intervals, and the computer determined in each interval whether the two observers agreed on the direction of the infant's gaze. Inter-observer agreement was measured for 60 of the 64 infants (for 4 of the infants, only one observer was present) and was calculated for each test trial on the basis of the number of intervals in which the computer registered agreement out of the total number of intervals in the trial. Agreement averaged 92% per test trial per infant.

Preliminary analyses were conducted for each of the experiments reported herein to explore whether males and females responded differently to the test events. These analyses failed to reveal reliable sex differences. Consequently, in this and the following experiments the data were collapsed across sex.

2.2. Results

2.2.1. Pretest trials

The infants' looking times during the four pretest trials were averaged and analyzed by means of an ANOVA with spoon color (green and red or yellow and blue) and test event (narrow or wide screen) as between-subjects factors. The main effects of spoon color and test event and the interaction between these two factors were not significant, all $Fs(1,60) < 1.3$, indicating that the infants in the four conditions did not differ reliably in their mean looking times during the pretest trials (green and red spoons, narrow-screen, $M = 24.8$, $SD = 4.4$, and wide-screen, $M = 25.4$, $SD = 3.7$; yellow and blue spoons, narrow-screen, $M = 27.1$, $SD = 3.7$, and wide-screen, $M = 25.4$, $SD = 4.5$).

2.2.2. Familiarization trials

The infants' looking times during the six familiarization trials were averaged and analyzed in the same manner as the pretest trials. The main effects of spoon color, $F(1,60) = 2.72$, $p > .05$, and test event, $F(1,60) < 1$, and the interaction between these two factors, $F(1,60) < 1$, were not significant, indicating that the infants in the four conditions did not differ reliably in their mean looking times during the familiarization trials (green and red spoons, narrow-screen, $M = 33.7$, $SD = 10.0$, and wide-screen, $M = 28.7$, $SD = 6.7$; yellow and blue spoons, narrow-screen, $M = 32.6$, $SD = 7.2$, and wide-screen, $M = 30.9$, $SD = 8.6$).

2.2.3. Test trials

The infants' looking times during the two test trials were averaged (Fig. 6) and analyzed in the same manner as the pretest and familiarization trials. The main effect of spoon color, $F(1,60) < 1$, was not significant. The main effect of test event, $F(1, 60) = 7.73$, $p < .01$, $\eta_p^2 = .11$, and the spoon color × test event interaction, $F(1,60) = 5.12$, $p < .05$, $\eta_p^2 = .08$, were significant. Planned contrasts indicated that the infants who saw the green

[4] In Experiments 1–4 infants saw the green ball–red ball test event with a narrow or a wide screen. Observers were asked to guess, at the end of each test session, whether the infant saw a narrow- or a wide-screen test event. Of the 128 infants tested, 113 primary observers recorded a guess. Of the 113 guesses recorded, 54 were correct, a performance not significantly different from chance (cumulative binomial probability, $p > .05$).

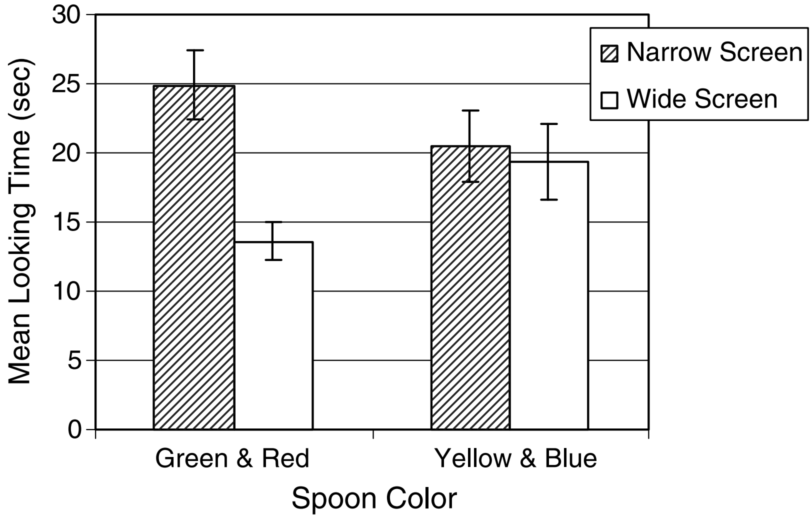

Fig. 6. Infants' mean looking times (with SE bars) during the test trials of Experiment 1, displayed for spoon color and test event (narrow or wide screen).

and the red spoons in the pretest trials looked reliably longer at the narrow-screen ($M = 24.9$, $SD = 10.0$) than at the wide-screen ($M = 13.6$, $SD = 5.6$) test event, $F(1, 60) = 12.65$, $p < .001$, Cohen's $d = 1.39$. A Mann–Whitney U-test confirmed that the distributions of these two groups were reliably different, $Z = -3.66$, $p < .001$ (2-tailed). In contrast, the infants who saw the yellow and the blue spoons in the pretest trials, looked about equally at the narrow-screen ($M = 20.5$, $SD = 10.3$) and the wide-screen ($M = 19.4$, $SD = 11.1$) test events, $F(1, 60) < 1$.

2.3. Discussion

The infants who saw the stir–lift events with the green and the red spoons looked reliably longer at the narrow- than at the wide-screen test event, suggesting that they individuated the green and the red ball. These results replicate those of the pound–pour experiments of Wilcox and Chapa (2004) and extend the color–function priming results to a novel pair of objects and functions. In contrast, the infants who saw the stir–lift events with the yellow and the blue spoons looked about equally at the two test events, suggesting that the infants in this condition failed to individuate the two balls. The fact that the infants demonstrated color priming to the colors seen in the pretest trials, but not to other colors, suggests that the infants linked object function to specific colors, rather than to color differences more generally, when viewing the stir–lift events. That is, infants formed a relatively specific representation of color–function events.

It is possible, however, that infants would demonstrate the capacity to form more abstract event representations, which generalize across color, under more supportive conditions. There is evidence from category learning experiments that the categories infants (Quinn et al., 1993) and adults (for reviews see Ashby & Ell, 2001; Ashby & Maddox, 2005; Markman & Ross, 2003) form in experimental settings are highly dependent on the exemplars seen. For example, when category exemplars are made more variable, infants' categorical representations become more inclusive (Quinn et al., 1993). Perhaps infants would be more likely to generalize to other colors in the test event if each pair of pretest events was seen with a different color pair. In other words, infants might form more abstract event categories if the exemplars of the relation between color and function were made more variable. Experiment 2 assessed this possibility.

3. Experiment 2

The goal of Experiment 2 was to assess the extent to which 9.5-month-olds would form more abstract event categories, and then generalize across color in the test events, if they were presented with category exemplars that varied in color. Infants were tested using the stir–lift procedure of Experiment 1 with one important difference: the first pair of spoons was yellow and blue and the second pair was purple and orange. If showing infants multiple color pairs in the stir–lift events leads them to form more inclusive event categories, and this influences infants' use of color information in the test events, then the infants should successfully individuate the green and the red ball in the test trials. In contrast, if showing infants multiple color pairs in the pretest events fails to facilitate the formation of more inclusive categories, then the infants should fail to individuate the green and the red ball in the test trials.

To our surprise, initial inspection of the data indicated that "old" 9.5-month-olds (9 months, 13 days to 10 months, 5 days) responded differently to this manipulation than "young" 9.5-month-olds (8 months, 22 days to 9 months, 12 days). Hence, we included age as a factor in our analysis. For ease in discussion, we will refer to these two age groups as 9.5-month-olds and 9-month-olds, respectively.

3.1. Method

3.1.1. Participants

Participants were 14 healthy 9-month-olds, 6 male and 8 female (M age = 9 months, 1 day; range = 8 months, 22 days to 9 months, 12 days), and 14 healthy 9.5-month-olds, 8 male and 6 female (M age = 9 months, 20 days; range = 9 months, 13 days to 10 months, 2 days). Eight additional infants were tested but eliminated from the analysis because of sleepiness ($N = 1$), crying ($N = 2$), procedural difficulties ($N = 4$), or family history of colorblindness ($N = 1$). Seven infants were pseudo-randomly assigned to each of four conditions formed by crossing test event (narrow or wide screen) and age (9 or 9.5 months): narrow-screen 9 months (M age = 9 months, 1 day; 4 M, 3 F); wide-screen 9 months (M age = 9 months, 1 day; 4 M, 3 F); narrow-screen 9.5 months (M age = 9 months, 18 days; 3 M, 4 F); wide-screen 9.5 months (M age = 9 months, 22 days; 3 M, 4 F).

3.1.2. Apparatus and stimuli

The apparatus and the pretest, familiarization, and test objects were identical to those of Experiment 1 with one exception. The first pair of spoons (serving spoons) was painted yellow and blue and the second pair (spaghetti spoons) was painted purple and orange. The purple spoon approximated the hue 2.5RP 2.5/4 of the Munsell Matte Collection (Munsell, 2005) and the orange spoon approximated the hue 7.5R 5/12.

3.1.3. Events and procedure

The events and procedure were identical to those of Experiment 1 except that the first pair of stir–lift events was seen with the yellow and blue serving spoons and the second pair was seen with the purple and orange spaghetti spoons. Inter-observer agreement was measured for 25 of the 28 infants and averaged 93% per test trial per infant.

3.2. Results

3.2.1. Pretest trials

The infants' looking times during the four pretest trials were averaged and analyzed by means of an ANOVA with test event (narrow or wide screen) and age (9 or 9.5 months) as between-subjects factors. The main effect of test event and the test event × age interaction were not significant, $Fs(1,24) < 1$. The main effect of age was significant, $F(1,24) = 4.63$, $p < .05$. The 9.5-month-olds ($M = 27.8$, $SD = 2.6$) looked longer during the pretest trials than the 9-month-olds ($M = 25.4$, $SD = 3.1$).

3.2.2. Familiarization trials

The infants' looking times during the six familiarization trials were averaged and analyzed in the same manner as the pretest trials. The main effects of test event and age, $Fs(1,24) < 1$, and the interaction between these two factors, $F(1,24) = 2.70$, $p > .05$, were not significant, indicating that the infants in the four conditions did not differ reliably in their mean looking times during the familiarization trials (9.5-month-olds, narrow-screen, $M = 29.3$, $SD = 3.9$, and wide-screen, $M = 36.5$, $SD = 6.9$; 9-month-olds, narrow-screen, $M = 33.3$, $SD = 8.9$, and wide-screen, $M = 31.3$, $SD = 8.7$).

3.2.3. Test trials

The infants' looking times during the two test trials were averaged (Fig. 7) and analyzed in the same manner as the pretest and familiarization trials. The main effects of test event, $F(1,24) = 3.64$, $p > .05$, and age, $F(1,24) < 1$, were not significant. The test event × age interaction, $F(1,24) = 6.65$, $p < .025$, $\eta_p^2 = .22$, was significant. Planned contrasts indicated that the 9.5-month-olds looked reliably longer at the narrow-screen ($M = 26.5$, $SD = 10.7$) than at the wide-screen ($M = 13.4$, $SD = 6.3$) test event, $F(1,24) = 10.15$, $p < .01$, Cohen's $d = 1.49$. A Mann–Whitney U-test confirmed that the distributions of these two groups

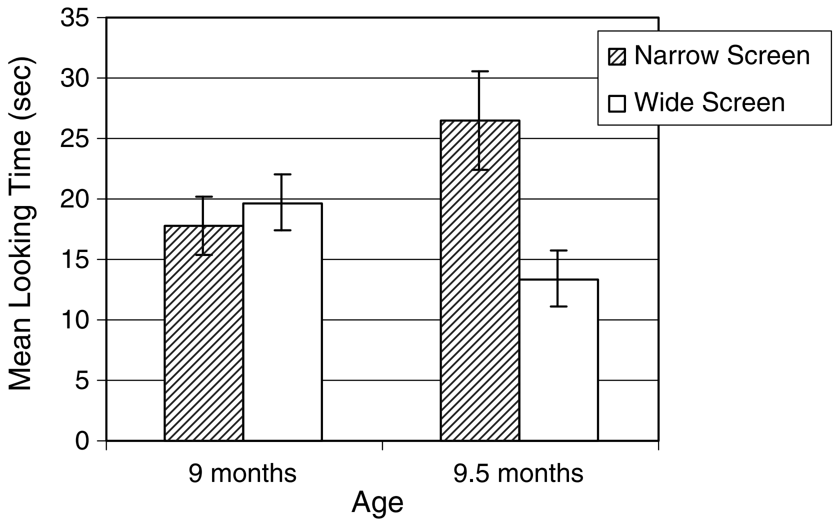

Fig. 7. Infants' mean looking times (with SE bars) during the test trials of Experiment 2, displayed for age and test event (narrow or wide screen).

were reliably different, $Z = -1.79$, $p < .05$ (1-tailed). In contrast, the 9-month-olds looked about equally at the narrow-screen ($M = 17.7$, $SD = 6.4$) and the wide-screen ($M = 19.7$, $SD = 6.3$) test events, $F(1, 24) < 1$.

Given that the analysis of the pretest data yielded a significant main effect of age, the test data were subjected to an analysis of covariance (ANCOVA); the factors were the same as in the ANOVA and the covariate was the infants' mean pretest looking times. The purpose of this analysis was to determine whether the same test results would obtain after adjusting for the difference in pretest looking times between the 9- and 9.5-month-olds. The results of the ANCOVA replicated those of the ANOVA: the main effects of screen, $F(1, 24) = 3.15$, $p > .05$, and age, $F(1, 24) < 1$, were not significant. The test event × age interaction, $F(1, 24) = 6.18$, $p < .025$, $\eta_p^2 = .21$, was significant. Hence, even when group differences in pretest looking times were controlled for, the test analysis yielded a significant test event × age interaction.

3.2.4. Additional analyses

The results obtained in Experiment 2 led us question the extent to which age differences existed in Experiment 1, since we did not statistically test for these differences. To assess this possibility, we re-analyzed the test data obtained in Experiment 1 by means of an ANOVA with spoon color (green and red or yellow and blue), test event (narrow or wide screen), and age (9 or 9.5 months) as between-subjects factors. An equal number of infants fell into each of the eight conditions formed by crossing these three factors. The main effect of test event, $F(1, 56) = 7.41$, $p < .01$, and the spoon color × test event interaction, $F(1, 56) = 4.91$, $p < .05$, were significant. The main effect of age, and all interactions involving age, $Fs(1,56) < 1$, were not significant. Together, these results indicate the performance of the 9- and 9.5-month-olds in Experiment 1 did not vary reliably. More specifically, in the green/red spoons condition both age groups were primed by the stir–lift events to attend to color differences in the test events (9.5-month-olds narrow-screen, $M = 23.1$, $SD = 10.2$, and wide-screen, $M = 14.3$, $SD = 7.4$; 9-month-olds narrow-screen, $M = 26.7$, $SD = 4.8$, and wide-screen, $M = 12.9$, $SD = 3.6$). In the yellow/blue spoons conditions, both age groups failed to use the color difference to individuate the green and red ball in the test event (9.5-month-olds narrow-screen, $M = 18.9$, $SD = 9.1$, and wide-screen, $M = 18.2$, $SD = 8.5$; 9-month-olds narrow-screen, $M = 22.2$, $SD = 11.6$, and wide-screen, $M = 20.6$, $SD = 13.7$).

3.3. Discussion

In Experiment 2, the infants saw two color pairs (yellow/blue and purple/orange) in the pretest events, and these color pairs differed from the color pair (green/red) seen in the test event. The 9.5- and 9-month-olds responded differently to this manipulation. The 9.5-month-olds successfully individuated the green and the red ball in the test trials, whereas the 9-month-olds failed to do so. These results suggest two conclusions. First, after viewing events in which different-colored objects perform different functions, 9.5-month-olds extract from the experience that color differences, more generally, are an important source of information and then attend to novel colors in the test events. Second, there is an important transition during the 9th month of life in infants' capacity to form more inclusive event categories when presented with more variable exemplars. Whereas 9.5-month-olds, after viewing multiple color pairs, successfully form event categories that generalize across color, younger 9-month-olds are unable to extract from the experience that color differences are relevant.

Why did the 9-month-olds fail to form event categories linking color to function? What is the underlying basis for 9-month-olds' difficulty in forming more inclusive event categories? One possibility is that because the spoons changed color on each pretest trial, the younger infants had difficulty keeping track of which spoon did what in each pair. If infants were unable to identify the relation between color and function, they would not have the information necessary to form an event category (much less form an event category that generalized across color). This analysis predicts that if infants were tested under conditions that facilitated the identification of this relation, they would be more likely to form an abstract categorical event representation. Another possibility is that younger infants can identify the relation between color and function within the context of this task, but are slower to do so. Perhaps if the younger infants were shown an additional exemplar pair, they would be able to identify this relation and then build the relevant (and more abstract) category. The next two experiments test these hypotheses.

4. Experiment 3

Experiment 3 assesses the extent to which 9-month-olds can be led to form more inclusive event categories if the relation between the different-colored spoons in each pair, and the function in which they engage, is made more explicit. There is evidence that infants 3–18 months demonstrate enhanced performance on categorization tasks when they are allowed to directly compare exemplars than when they are presented with exemplars one at a time (Namy, Smith, & Gershkoff-Stowe, 1997; Needham, 2001; Needham, Dueker, & Lockhead, 2005; Oakes & Ribar, 2005; Quinn, 1987). Gentner and Namy (1999) argued that the process of comparison facilitates the extraction of deeper and more abstract relations among category members. Indeed, recent priming studies have revealed that direct comparison of exemplars during pound–pour events facilitates the formation of more inclusive event categories and enhances priming effectiveness. Recall that it is not until 7.5 months that infants spontaneously use pattern differences to individuate objects (Wilcox, 1999; see also Needham, 1999). Using the pound–pour procedure Wilcox and Chapa (2004) assessed the extent to which 5.5- and 4.5-month-olds can be primed to individuate objects on the basis of pattern differences. 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 narrow- or wide-screen 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 provide converging evidence for the conclusion that direct comparison of exemplars is highly effective in facilitating the formation of more inclusive categories in infants.

On the basis of these findings, we tested 9-month-olds using the stir–lift procedure with the yellow/blue and the purple/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 and in full view, next to the bowl being lifted. If seeing the spoons of each pair together during the pretest events facilitates the formation of more inclusive event categories that generalize across color, then the 9-month-olds in Experiment 3 should demonstrate color priming in the test trials. In contrast, if seeing the spoons of each pair together during the pretest events does not lead 9-month-olds to form more inclusive event categories, then the 9-month-olds in Experiment 3 should fail to demonstrate priming to red and green in the test trials.

4.1. Method

4.1.1. Participants

Participants were 16 healthy 9-month-olds, 8 male and 8 female (M age = 9 months, 0 days; range = 8 months, 20 days to 9 months, 11 days. Four additional infants were tested but eliminated from the analysis because of crying ($N = 2$) or procedural difficulties ($N = 2$.)). Eight infants (4 M, 4 F) were pseudo-randomly assigned to each of two conditions: narrow-screen or wide-screen.

4.1.2. Apparatus and stimuli

The apparatus and the pretest, familiarization, and test objects were identical to those of Experiment 2.

4.1.3. Events and procedure

The events and procedure was identical to that of Experiment 2 except that the spoons of each pair were presented together during the pretest events. During the stir event, the blue (or the purple) spoon sat propped up on a metal stand, in full view, 11 cm to the left of the bowl with the salt. During the lift event, the yellow (or the orange) spoon sat propped up 11 cm to the left of the bowl that was being lifted. Inter-observer agreement was measured for 14 of the 16 infants and averaged 94% per test trial per infant.

4.2. Results

4.2.1. Pretest trials

The infants' looking times during the four pretest trials were averaged and analyzed by means of an ANOVA with test event (narrow or wide screen) as the between-subjects factor. The main effect of test event was not significant, $F(1, 14) < 1$, indicating that the infants in the narrow-screen ($M = 27.2$, $SD = 2.6$) and the wide-screen ($M = 25.9$, $SD = 3.5$) condition looked about equally during the pretest trails.

4.2.2. Familiarization trials

The infants' looking times during the six familiarization trials were averaged and analyzed in the same manner as the pretest trials. The main effect of test event was not significant, $F(1, 14) < 1.3$, indicating that the infants in the narrow-screen ($M = 36.6$, $SD = 7.9$)

and the wide-screen ($M = 32.7$, $SD = 5.8$) condition looked about equally during the familiarization trails.

4.2.3. Test trials

The infants' looking times during the two test trials were averaged (Fig. 8) and analyzed in the same manner as the pretest and familiarization trials. The main effect of test event was significant, $F(1,14) = 7.79$, $p < .025$, $\eta_p^2 = .36$, indicating that the infants in the narrow-screen condition ($M = 23.3$, $SD = 9.7$) looked reliably longer during the test event than the infants in the wide-screen condition ($M = 12.6$, $SD = 4.8$). A Mann–Whitney *U*-test confirmed that the distributions of these two groups were reliably different, $Z = -2.21$, $p < .05$.

The prediction was made that viewing the spoons together during the pretest events would significantly improve performance on the test events. To assess the extent to which the 9-month-olds who saw the spoons together in the pretest events (Experiment 3) demonstrated a different pattern of looking during the test events than the 9-month-olds who did not see the spoons together in the pretest events (Experiment 2), an additional analysis was conducted in which the test data were analyzed by means of an ANOVA with Experiment (2 or 3) and test event (narrow or wide screen) as between-subjects factors. The main effect of screen, $F(1,26) = 2.84$, $p > .05$, and test event, $F(1,26) < 1$, were not significant. The experiment × test event interaction was significant, $F(1,26) = 5.94$, $p < .025$, $\eta_p^2 = .19$, indicating that the 9-month-olds in Experiment 2 and Experiment 3 responded differently to the test events. The 9-month-olds in Experiment 3 looked longer at the narrow- than at the wide-screen test event (i.e., successfully individuated the green and the red ball), whereas the 9-month-olds in Experiment 2 looked about equally at the two test events (i.e., failed to individuate the balls).

4.2.3.1. Additional results. The main procedural difference between Experiments 2 and 3 was that in the former, only one spoon (i.e., the spoon that engaged in the function) was seen in each pretest trial, whereas in the latter both spoons were seen in each pretest trial. This manipulation was designed so that infants had the opportunity to see the spoons of each pair simultaneously, highlighting the functional difference between the two colors in each pair. However, this manipulation also gave infants twice as much exposure to each

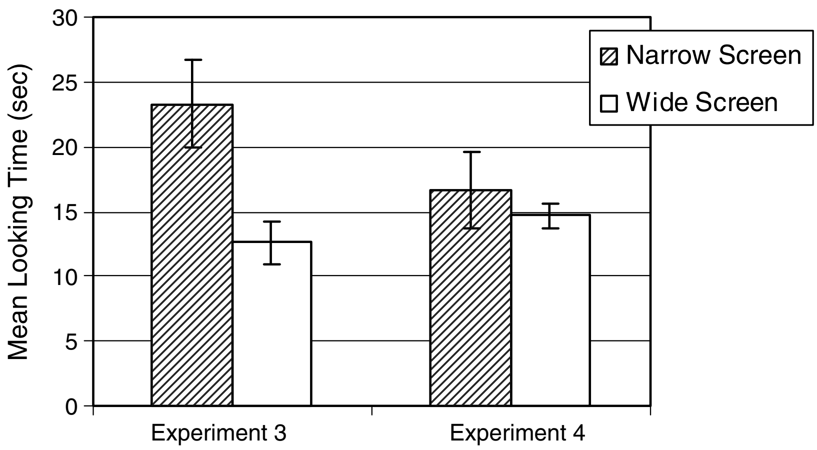

Fig. 8. Infants' mean looking times (with SE bars) during the test trials of Experiment 3 (direct comparison) and Experiment 4 (additional exemplar pair) displayed for test event (narrow or wide screen).

spoon. It is possible that additional time to encode each spoon, rather than seeing the spoons together, led to improved performance. To assess this possibility, infants were tested using a similar stir–lift procedure except that the spoons were seen together during the first 8 s of each pretest trial only. After 8 s (one complete cycle of the stir or the lift event) a screen was slid in front of the propped-up spoon so that it was completely occluded, and remained so for the duration of the pretest trial. Hence, infants saw the spoons together only briefly at the beginning of each pretest trial, so that the amount of extra exposure to each spoon was decreased from 30 to 8 s. Infants ($N = 6$; 2 M, 4 F; M age = 9 months, 2 days) were tested in the narrow-screen condition only.

The mean looking times of the infants in the narrow-screen control condition of Experiment 3 (8 s of simultaneous viewing of the spoons during the pretest trials) were compared to those of the narrow-screen condition of Experiment 2 (no simultaneous viewing of the spoons) and the narrow-screen condition of Experiment 3 (30 s of simultaneous viewing of the spoons). A one-way ANOVA revealed no significant effect of condition on looking times during the pretest events (narrow-screen control, $M = 27.8$, $SD = 2.6$), $F(1,22) < 1$, and the familiarization event (narrow-screen control, $M = 33.4$, $SD = 10.1$), $F(1,22) < 1$. In contrast, planned contrasts indicated that the looking times of the infants in the narrow-screen control condition of Experiment 3 ($M = 25.7$, $SD = 15.4$) differed reliably from those of the narrow-screen condition of Experiment 2, $t = 2.02$, $df = 12$, $p = .046$ (1-tailed, equal variances not assumed), but not from those of the infants in the narrow-screen condition of Experiment 3, $t < 1$, $df = 12$. Hence, even when infants were given less time to view the spoons together during the pretest events they still benefited from the simultaneous presentation procedure. These results suggest that the outcome of Experiment 3 is better explained by the opportunity to directly compare the spoons of each exemplar pair, if only briefly, than by additional time to encode each spoon during the pretest trials. It is unlikely that just a few extra seconds of encoding time for each object would lead to such drastically improved memory performance.

Finally, one might be concerned that seeing the spoons together during the pretest events simply signaled to the infants that two of each object would be present in each event. That is, on the basis of evidence that two objects were involved in the pretest events infants would infer that two objects were also involved in the test events. Although possible, recent studies using a different type of priming paradigm with 10.5-month-olds suggest this explanation is unlikely (Wilcox et al., 2007; also see Wilcox & Woods, in press). The outcome of these studies indicate that viewing a green ball and a red ball simultaneously in a different situation (e.g., outside of the apparatus and/or in a different room) prior to the test trials does not lead infants to infer the presence of two balls in a green ball–red ball occlusion event. That is, infants do not use the spatiotemporal information from the first situation, which indicates the presence of two objects, to predict the number of objects involved in the second situation. In light of this evidence, it is unlikely that the 9.5-month-olds in the present experiments inferred that two balls were involved in the test events after being shown that two numerically distinct spoons were involved in the pretest events.

4.3. Discussion

In Experiment 3 the 9-month-olds were presented with both spoons together during the pretest events, giving them the opportunity to directly compare the spoons of each stir–lift pair. This experience led to improved performance: the 9-month-olds successfully individuated the green and the red ball in the test events. These results contrast sharply with those obtained in Experiment 2, where infants saw only one spoon at a time. When infants were not allowed to directly compare the spoons in each exemplar pair they failed to individuate the balls in the test event. We propose that seeing the spoons side-by-side during the stir–lift events made explicit the relation between the spoons in each pair. Once the 9-month-olds had successfully identified this relation—different-color spoons engage in different functions—they demonstrated sensitivity to novel color pairs in the test events. Data collected in an additional condition, in which infants saw the spoons together for only 8 s at the beginning of each pretest trial, provide converging evidence for this interpretation of the data and suggest that the effects of direct comparison are robust, requiring only a modest amount of simultaneous exposure to the spoons.

Why does direct comparison of exemplars facilitate the formation of more inclusive categories? Why does seeing the blue and yellow (and purple and orange) spoon side-by-side make more explicit the relation between color and function? Gentner and her colleagues (Gentner, 1983; Gentner & Gunn, 2001; Gentner & Markman, 1994; Gentner & Medina, 1998; Markman & Gentner, 1997, 2000) have argued that when attempting to map one event representation onto another, there are multiple strategies that can be invoked. One strategy is to focus on the objects themselves, and to identify whether the object in the first event (e.g., blue spoon) maps onto the object in the second event (e.g., yellow spoon). This requires identifying similarities and differences between the two objects to determine the extent to which they map one onto the other. Since this is the simplest and most straightforward approach, typically children and adults first try to map objects when viewing a succession of events. In the stir–lift experiments, this involves identifying the extent to which the spoon in the stir event maps onto the spoon in the lift event. Since the two spoons were identical in their appearance except for their color, and infants of this age are not particularly sensitive to object color in and of itself, object-mapping did not facilitate the formation of an event category that included color differences. An alternative approach is to focus on the relation between sources of information within each event (e.g., the relation between color and function) and identify whether the relational structure of one event maps onto that of another. This is a more sophisticated, and more effective, strategy. In the stir–lift events, this means identifying the relation between the color of the spoon and the function in which it engages. Clearly, the younger 9-month-olds had difficulty extracting this relation when viewing the events one at a time. Seeing both spoons in the apparatus simultaneously served to focus infants' attention on the relational structure of the currently viewed event (e.g., the green spoon stirs) and highlight the fact this event differs in structure from the other event (e.g., the red spoon does not stir). In other words, direct comparison gave infants the opportunity to identify the relevant information and to use it to form representations that captured the relational structure of the events.

5. Experiment 4

The outcome of Experiment 3 indicates that one way to facilitate 9-month-olds formation of more abstract categorical event representations is to allow infants to directly compare exemplars in the pretest events. Experiment 4 takes a different approach to facilitating categorization in 9-month-olds. Recall that in Wilcox and Chapa (2004) 9.5-month-olds benefited from the pound–pour procedure (i.e., demonstrated color priming) after viewing two pairs of pound–pour events, whereas 7.5-month-olds needed to see three pairs of pound–pour events. Perhaps 9-month-olds would be more likely to succeed on this more challenging categorization task if they were shown an additional exemplar pair. To assess this possibility, 9-month-olds were tested using the procedure of Experiment 2 with one important difference: infants saw a third pair of stir–lift events with another color pair.

5.1. Method

5.1.1. Participants

Participants were 14 healthy 9-month-olds, 8 male and 8 female M age = 9 months, 1 day; range = 8 months, 20 days to 9 months, 12 days. One additional infant was tested but eliminated from the analysis because of family history of colorblindness. Eight infants were pseudo-randomly assigned to each of two conditions: narrow-screen or wide-screen.

5.1.2. Apparatus and stimuli

The apparatus and the pretest, familiarization, and test objects were identical to those of Experiment 2 except for a third pair of spoons. The spoons were brown and cream ladles. Each ladle was 29.5 cm long. The scoop of each spoon was 9 cm wide at the widest point, 7.5 cm long and 3.5 cm deep. The handle was 2.5 cm wide, 22 cm long, and.5 cm thick. At the end of each handle was a small hole, 1 cm wide and 1.75 cm long. The brown spoon approximated the hue 10R 3/4 of the Munsell Matte Collection (Munsell, 2005) and the cream spoon approximated the hue 2.5Y 8/2.

5.1.3. Events and procedure

The events and procedure were identical to that of Experiment 2 except that infants saw a third pair of pretest events with the brown and the cream spoon. The brown spoon stirred and the cream spoon lifted. Inter-observer agreement was measured for 13 of the 14 infants and averaged 92% per test trial per infant.

5.2. Results

5.2.1. Pretest trials

The infants' looking times during the six pretest trials were averaged and analyzed by means of an ANOVA with test event (narrow or wide screen) as the between-subjects factor. The main effect of test event was not significant, $F(1, 12) < 1$, indicating that the infants in the narrow-screen ($M = 26.6$, $SD = 2.6$) and the wide-screen ($M = 25.7$, $SD = 2.4$) condition looked about equally during the pretest trials.

5.2.2. Familiarization trials

The infants' looking times during the six familiarization trials were averaged and analyzed in the same manner as the pretest trials. The main effect of test event was not significant, $F(1, 12) < 2$, indicating that the infants in the narrow-screen ($M = 26.7$, $SD = 4.7$) and the wide-screen ($M = 31.5$, $SD = 8.6$) condition looked about equally during the familiarization trails.

5.2.3. Test trials

The infants' looking times during the two test trials were averaged (Fig. 8) and analyzed in the same manner as the pretest and familiarization trials. The main effect of test event was not significant, $F(1,12) < 1$, indicating that the looking times of the infants in the narrow-screen ($M = 16.7$, $SD = 7.8$) and the wide-screen ($M = 14.7$, $SD = 2.5$) conditions did not differ reliably. A Mann–Whitney U-test confirmed that the distributions of these two groups not differ reliably, $Z = -0.64$, $p > .05$. These results suggest that exposure to an additional exemplar in the pretest events did not improve performance on the test events.

5.3. Discussion

In contrast to the positive results obtained in Experiment 3, where 9-month-olds were allowed to directly compare the stir–lift spoons, null results were obtained in Experiment 4, where 9-month-olds were presented with an additional pair of stir–lift events. These results suggest two conclusions. First, viewing an additional exemplar pair does not facilitate the formation of more inclusive event categories in 9-month-olds. Even after viewing three different pairs of different-colored spoons engaged in the stir and lift events, the 9-month-olds failed to attend to color differences in the test events. This outcome is consistent with the outcome of pattern priming experiments conducted with younger infants. Recall that infants first spontaneously use pattern differences as the basis for object individuation at 7.5 months (Wilcox, 1999). Follow-up studies revealed that whereas 5.5-month-olds were primed to attend to pattern differences (dotted ball-striped ball) after viewing three pairs of pretest events (dotted containers pounded and striped containers poured), 4.5-month-olds were primed to attend to patterns differences only after seeing the pretest objects simultaneously during the pretest events (Wilcox & Chapa, 2004). Simply viewing additional pairs of pretest events did not facilitate pattern priming in the younger infants. There is now a growing body of evidence indicating that the extent to which infants can be lead to attend to new sources of information within the context of physical events depends on the information to be primed, the nature of the task, and the age of the infant (Baillargeon, 2004; Baillargeon & Wang, 2002; Wang & Baillargeon, 2005; Wilcox & Chapa, 2004).

Second, the developmental shift after 9 months in infants' performance in this priming task is better explained by the capacity to identify the relation between color and function than the speed or efficiency with which they do so. Having one more opportunity to identify the relation between color and function was not sufficient to prime the younger 9-month-olds to attend to color differences in the test events (see Wilcox & Chapa, 2004 for similar results with younger infants). The 9-month-olds generalized across color pairs and demonstrated sensitivity to color differences in the test events only when they were allowed to directly compare the different-colored spoons during the pretest events. The experience of seeing the spoons simultaneously provided an opportunity through which the infants could more easily identify the relevant similarities and differences between the objects. For example, seeing the spoons side-by-side made clear that the spoons in each pair were identical in many ways, including their shape, size, composition, and surface texture. At the same time, the spoons differed on two dimensions: color and the function in which they engaged (e.g., only the yellow/purple spoon stirred and only the blue/orange spoon lifted). Once these similarities and differences were identified, infants could extract the relational structure of the events—different-colored spoons engage in different functions—and subsequently demonstrated increased sensitivity to color differences in the test events. What we are suggesting, then, is that the main difference between the 9- and 9.5-month-olds is that the younger infants experienced greater difficulty in identifying and representing the relational structure of the stir–lift events. However, when the structural similarities between the two events were made more obvious, by allowing infants to directly compare parts of the events, the mapping of the event structures was made possible.

6. General discussion

Cognitive scientists have long puzzled over questions about the origins and development of object knowledge. What knowledge is present early in development? How does knowledge change with time and experience? The goal of the present experiments was to shed light on this debate by identifying conditions under which infants' sensitivity to color information, which is slow to emerge, could be enhanced. The outcome of Experiment 1 confirmed and extended previous reports that 9.5-month-olds can be primed, through exposure to events in which the color of an object predicts its function, to attend to color differences in a subsequent individuation task. The outcomes of Experiments 2–4 revealed age-related changes in the nature of the representations that support color priming. This is exemplified by three main findings. First, the representations that are formed during the color–function (i.e., stir–lift) events are relatively specific. That is, infants are primed to use the color difference seen in the color–function events to individuate objects in the test events, but not other color differences. Second, 9.5-month-olds can be led to form more abstract event representations, and then generalize to other colors in the test events if they are shown multiple pairs of colors in the color–function events. Third, slightly younger 9-month-olds also can be led to form more inclusive categories with multiple color pairs, but only when they are allowed to directly compare the exemplars in each color pair during the present events.

Together, the outcomes of these experiments provide insight into the nature and content of the categorical event representations that are formed during the color–function events, the conditions under which these representations support color priming, and the cognitive mechanisms involved. In addition, these findings shed light on the kinds of experiences that can alter the type of information to which infants attend when individuating objects. The remainder of the discussion will focus on these issues.

6.1. Infants' formation and use of categorical event representations

Perhaps most intriguing about the color–function results is that they illustrate ways in which the naive human mind attempts to make sense of the world around them. When observing physical events, such as spoons stirring or cups pouring, infants attempt to identify regularities and then build object and event categories on the basis of these regularities. At the same time, infants do not attend to all associations or regularities. We employed stirring and lifting in the present experiments on the account of Wilcox and Chapa (2004; also see Booth and Waxman, 2002a), who reported that infants demonstrate color priming only when the actions the objects perform are functionally relevant. Given the wide array of information to which infants could attend when viewing physical events, and their limited information processing resources, it makes sense that infants would be biased to attend to information that is potentially useful when interacting with the objects, and that could help in the interpretation of and the learning about physical events. As Markman and Ross (2003) argue, even in experimental settings when adults are given novel information to classify, participants are not simply ''forming categories, but rather are generating representations that are useful for the task they have been given.'' That is, adults form a representation of a category based on what they perceive to be relevant features and then use these categories to classify new exemplars, or perhaps to make inferences about the properties new exemplars possess. We propose that when viewing the color–function events infants engage in a similar process: they generate representations based on what they perceive to be relevant relations (i.e., the link between color and function). These representations allow them to predict, in any given event, which spoon will engaged in which function, and might also be useful in interpreting upcoming events with novel exemplars.

The stir–lift results also reveal that the extent to which regularities can be identified when forming event categories, and the nature of the event categories formed, depends on the exemplars seen. When the exemplars (i.e., pairs of spoons) were all of the same-color pair infants' event categories were relatively specific: infants generalized to the color pair seen in the pretest events but not to other color pairs. However, when the exemplar pairs were more variable, when 9.5-month-olds saw two different color pairs (yellow/blue and purple/orange) in the pretest events, they successfully generalized to another color pair (green/red) in the test events. This finding is consistent with what we know about category learning in infants and adults. Across a wide range of tasks and experimental conditions, investigators have reported that when infants and adults form new categories, the nature of the categories formed is dependent on the exemplars seen (Ashby & Ell, 2001; Ashby & Maddox, 2005; Markman & Ross, 2003; Quinn et al., 1993). One advantage of this type of category learning is that it allows flexibility in category structure; as the exemplars change so does the structure of the category. This facilitates the shaping of categories to be maximally useful, and closely tied to, the current situation. Although not all categories are formed in this way (see *What Kinds of Categories are these?)*, this process allows for maximum flexibility is how infants classify and interpret incoming information.

At the same time, the stir–lift results raise questions about the conditions under which infants will use feature–function pairings as the basis for forming categorical event representations. Recall that we defined function as an agent produced action on an object that the object affords and/or for which it was intended, either by design or through conventional use. In addition, the relation between an object's parts and the function in which it engages must be causal in nature. Hence, object function is multifaceted: it involves affordances of an object and its parts, experience with objects of that type, and causal relations. We suspect that the stir–lift (and pound–pour) procedure was effective because infants saw events that contained all of these components: the spoons' structure was related to its function (e.g., a hole in the handle was required for lifting the bowl and the concave part of the spoon facilitated stirring), the function of the spoons was demonstrated by an experimenter, and the events contained a causal structure. What is the relative contribution of each of these components to color–function priming? One way to answer this question is to examine the role that each of these factors play in infants' and children's understanding of object function.

There is evidence that young children are very sensitive to the relation between an object's parts and its function (i.e., the affordance of objects). For example, children 2–4 years are more likely to form categories on the basis of object function (Kemler Nelson, Frankenfield et al., 2000), extend labels to novel objects (Kemler Nelson, 1995, 1999; Kemler Nelson, Russell et al., 2000), and engage in successful problem-solving (Kemler

Nelson, 1999) if the relation between the objects' parts is directly and simply related to its function. Furthermore, these effects are often more robust when the function in which an object engages provides a clear and plausible causal account of the object's perceptible structure (Booth, 2006; Kemler Nelson et al., 2000). These results are not all that surprising, given the fact that, except for the most complex of tools and other artifacts, there is usually a close causal relation between perceptible structure and conventional use. Finally, older infants have difficulty detecting correlations between object parts and outcomes when this relation is arbitrary (e.g., pushing the top of an object causes the object to whistle; Madole & Cohen, 1995; Madole, Oakes, & Cohen, 1993). When it is difficult for older infants to ascertain the way in which the structure of the object affords an outcome, and the causal mechanism involved, they do not readily link object parts to outcome. Together, these results lead us to predict that object affordances and causal structural are both integral to color–function priming. This prediction is supported, in part, by the fact that from an early age infants are sensitive to the causal structure of events (Baillargeon, Kotovsky, & Needham, 1995; Koslowski & Masnick, 2002; Leslie, 1988; Premack, 1995; Sobel & Kirkham, 2006) and recognize when the relation between cause and effect has been violated.

What is left open to speculation is the role that experience plays in infants' reasoning about object function. In young children and adults, experience with an object, or a category of objects, plays an important role in reasoning about object function. For example, domain-specific knowledge about a type of object can facilitate children's and adults' capacity to categorize objects on the basis of function (e.g., Keil, 1989; Kemler Nelson, 1999; Medin, 1989). In addition, knowing the function for which an object was intended, and seeing this function demonstrated, is a salient source of information to young children. They use information gained through these experiences to form expectations about the purpose for which similar objects were designed and to inform tool choices in problem-solving situations (Casler & Kelemen, 2007). However, little is known about the extent to which experiential factors influence infants' reasoning about object function. Although experience with tools, such as spoons, during the first year leads to greater skill and competence with those tools (e.g., Achard & von Hofsten, 2002; Connelly & Dalgleish, 1989; McCarty, Clifton, & Collard, 2000), the effect of this experience on infants' reasoning about object function, more generally, remains largely untested. There is evidence that when 12- to- 18-month-olds are given a familiar object (spoon) to complete a novel task (turn on a light in a box) they insist on holding the spoon by the handle, even when it makes solving the task impossible (Barrett, Davis, & Needham, 2007). A subsequent study revealed that infants' who were taught to use a novel tool to perform a novel function were able to use the tool in other ways, as long as the function they were required to perform involved grasping the tool in the same way. These data suggest that infants' tool use is better explained by "grasping fixedness" (a tendency to pick up familiar objects in ways that are familiar and practiced) than "functional fixedness" (a tendency to use familiar objects in ways that are familiar and practiced). In other words, infants probably do not possess the same tendency to focus on intention and design when thinking about and using tools that has been reported in children and adults (e.g., Bloom, 1996; Kelemnan, 1999; Matan & Carey, 2001).

The fact that spoons are typically used to lift food to the mouth and not lift bowls, yet color–functioning priming was obtained, suggests that prior experience with spoons (albeit more limited in 9.5-month-olds than 12-month-olds) did not prevent the infants from linking novel functions to the spoons. In addition, the infants were flexible in their reasoning about object function: they were not impaired by the fact that the same object (a spoon) engaged in different functions (stirring and lifting). We suspect that as long as function is effective, and parts and outcomes are causally related, priming will be obtained in infants. This is an empirical question, however, that will need to be resolved by future research.

6.2. The role of comparison in forming categorical event representations

The outcome of the present experiments also highlights the importance of comparison to the formation of event categories during the first year of life. Recall that the younger 9-month-olds demonstrated the capacity to generalize across color only when they were able to directly compare the spoons in each color pair during the stir–lift events. Even when the time allowed for comparison was limited, the experience of seeing the exemplars together was critical to color priming. This finding provides converging evidence that infants demonstrate enhanced categorization performance—are more likely to form categories and the categories are more abstract—when they are allowed to directly compare exemplars than when they are presented with exemplars one at a time (Namy et al., 1997; Needham, 2001, Needham et al., 2005; Oakes & Ribar, 2005; Quinn, 1987; Wilcox & Chapa, 2004). The facilitative effect of direct comparison obtained in Experiment 3 contrasts sharply with the null results obtained in Experiment 4. When the infants were shown an additional exemplar pair—an additional pair of pretest events with another set of colored spoons—they did not demonstrate increased sensitivity to color in the test events. That is, providing infants with another example of the relation between color and function failed to induce them to form an event representation in which color differences were linked, more generally, to object function.

These results suggest an important transition during the 9th month in infants' capacity to form categorical event representations. The color priming procedure presents infants with a relatively challenging categorization task. In order to form an event category that links color to function infants must identify whether the spoon currently in view differs in color from the previous spoon, whether the previous spoon stirred or lifted, and 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 would be unable to form a categorical representation of the stir–lift events. The fact that 9-month-olds demonstrated improved performance when the relation between the exemplars in the stir–lift events was made more transparent, but not when they were given more exemplars, suggests that the critical difference between the 9- and 9.5-month-olds is the capacity to identify and extract relevant category information and not the speed or efficiency with which they do so. Additional research is needed to establish the specific conditions under which younger infants can be led to identify and extract relevant category information. For example, perhaps the most important component of the simultaneous presentation procedure is seeing both spoons together. Seeing the spoons together highlights the fact that two distinct spoons are involved in the stir and lift events and that the spoons differ in color. This experience provides enough structure so that the infants can then attach a function to each colored spoon while viewing the stir–lift events. According to this hypothesis, brief exposure to the spoons together prior to the pretest events, without the performance of a function, should be sufficient to support color priming. Alternatively, perhaps it is the experience of seeing the specific function that each spoon engages in, while at the same time seeing the other spoon that is critical to color priming. That is, in order for infants to identify the relation between color and function, they need to see at least one of the spoons engaged in a function while viewing the other spoon. According to this hypothesis, color priming would only be observed when infants have had the opportunity to see the spoons together while at least one spoon is engaged in a function (i.e., simply seeing the spoons together, as proposed above, would not be sufficient to support color priming). Once we have identified the specific conditions that support color priming, and how this changes with time and experience, we will have a better understanding of the relation between comparison and categorization processes during the first year of life.

The importance of comparison to the formation and use of object and event categories extends well beyond infancy and color priming, however (e.g., Gentner & Medina, 1998; Gentner & Namy, 2004, 2006; Klibanoff & Waxman, 2000; Waxman & Klibanoff, 2000). For example, Klibanoff and Waxman (2000; Waxman and Klibanoff, 2000) investigated the extent to which comparison, and the formation of object categories, influenced the extension of novel adjectives in preschoolers. In one study (Klibanoff & Waxman, 2000), 3- and 4-year-olds were shown a target object and the experimenter used a novel adjective to describe the object (e.g., "The horse is blickish."). The preschoolers were then shown a pair of test objects from either the same basic level category (e.g., two horses) or a different basic level category (e.g., two rhinoceros) and were asked to chose the one (of the pair) that possessed the same property ("Give me the one that is blickish."). The 4-year-olds extended novel adjectives from target to test objects regardless of whether the objects were from the same or a different basic level category. In contrast, the 3-year-olds extended novel adjectives only to objects from the same basic level category. However, when 3-year-olds were given the opportunity to map novel adjectives to same-category objects, before they were asked to map them to different-category objects, they demonstrated improved performance (i.e., extended novel adjectives to objects from a different category). The opportunity to first engage in across-category mapping provided no such advantage. Why did the experience of mapping a novel adjective within (but not across) a basic level category enhance 3-year-olds' capacity to subsequently map a novel adjective across basic level categories? Klibanoff and Waxman (2000) suggested that seeing the target and test objects together provided infants with the opportunity to directly compare the objects and to identify ways in which the objects were the same and ways in which they were different (see Gentner & Gunn, 2001; Gentner & Markman, 1994; Gentner & Namy, 1999 for support for this proposal). When the target and test objects belonged to the same basic level category the objects were similar in many respects, making it easy for infants to identify relevant differences. Once the relevant differences were identified, the 3-year-olds readily extended the novel adjective to objects of a different basic level category. In contrast, without this experience, when the target and test objects were always from different basic level categories, the objects possessed fewer similarities, making it difficult for infants to identify the relevant differences. Because the 3-year-olds failed to identify the property to which the novel adjective referred, extension of the novel adjective was made impossible (see Waxman & Klibanoff, 2000 for additional evidence that comparison facilitates extension of novel adjectives beyond the basic level).

The Klibanoff and Waxman (2000) results have interesting implications for color–function priming. First, the results suggest that the pound–pour and stir–lift procedures that we have used to date have been effective because the two objects of each exemplar pair (whether spoons or containers) were very similar—in fact they were identical except for their color and the function in which they engaged. When objects differ on only two dimensions, and these dimensions are perfectly correlated, the comparison process is straightforward. Infants can easily extract the relation between the two properties. Second, the outcome of the Klibanoff and Waxman studies predict that if the objects were to differ on more than two dimensions (e.g., the green spoon was slotted and the red spoon was a ladle) performance would decline. With fewer similarities between the two spoons of each pair, and more differences, the comparison process would be more demanding. It would be difficult for infants to identify the relevant differences and color–function priming would fail.

The parallels between color-priming and adjective-learning strengthen the proposal that comparison is a general psychological process (Gentner & Markman, 1994; Gentner & Medina, 1998) that facilitates learning across a wide range of tasks and domains of knowledge. Broadly speaking, comparison facilitates learning by supporting the abstraction of commonalities and rules and by providing a mechanism by which this knowledge can be applied to new situations (Gentner & Medina, 1998). We have already specified the importance of comparison processes in object and language learning tasks with infants (also see Gentner & Namy, 2004, 2006). In children, comparison has been identified as important to analogical reasoning (Gentner & Namy, 2006; Gentner & Toupin, 1986), detecting relational similarities (Kotovsky & Gentner, 1996), spatial mapping (Loewenstein & Gentner, 2001), and the development of categories (Gentner & Namy, 1999). Finally, cognitive psychologists have investigated the importance of comparison to a number of cognitive functions, including analogy, memory, representational mapping (Gentner, 1983; Gentner & Gunn, 2001; Markman & Gentner, 1997, 2000). Together these results firmly establish comparison as an integral part of cognitive function, across the life span.

6.3. What kinds of categories are these?

How should we conceptualize the event categories that infants form during the stir–lift events? How do these categories compare to other kinds of categories that infants build and use? It is well documented that infants organize knowledge about the world and interpret incoming information on the basis of classification systems. For example, from an early age, infants possess perceptual categories that they use to help make sense of a wide range of perceptual stimuli, from speech sounds to color arrays (e.g., Aslin, Jusczyk, & Pisoni, 1998; Bornstein et al., 1976; Franklin & Davies, 2004). Infants also possess more meaningful or conceptual categories (Mandler, 1992), such as the distinction between kinds of objects (animate vs. inanimate or natural kinds vs. artifacts) or kinds of mechanical interactions (containment vs. support or inert vs. self-propelled), that allow them to interpret and make predictions about the outcome of physical and social events (e.g., Baillargeon, 1998, 2004; Leslie, 1994; Meltzoff & Moore, 1995; Premack, 1990; Spelke & Woodward, 1995). In adults, these are often referred to as natural categories (Ross & Murphy, 1999) and a great deal of effort has been placed on understanding how adults and children use these categories to draw inferences about the properties an object will possess or the purpose/function of an object (Gelman & Coley, 1990; Gelman & Koenig, 2003; Gelman & Markman, 1987; Kalish & Gelman, 1992; Lopez, Atran, Coley, Medin, & Smith, 1997; Malt, Rose, & Murphy, 1995; Malt & Smith, 1984; Markman, 1989; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976; Ross & Murphy, 1999). These kinds of categories are evident very early in development, are relatively stable, and are gradually shaped over time by infants' and children's everyday experiences in the physical and social world.

In contrast, the categories that infants form during the color–function priming task are quite different. These categories are created "on the fly" and represent an attempt to identify relations between seemingly unrelated sources of information in novel events. Cognitive neuroscientists working with adults have reported that the neural structures that are engaged during the processing of natural categories differ reliably from those that are engaged during the formation and use of artificially induced categories (Ashby & Ell, 2001; Ashby & Maddox, 2005). These results provide converging evidence for the idea that reasoning about and using natural categories and forming and using artificial categories engage very distinct categorization processes. One particularly intriguing aspect of these "on the fly" categories is that they have a powerful influence on how infants, and adults, think about and act on objects. According to the present results, the forming of categorical event representations that link together potentially relevant sources of information allows infants to organize events as they unfold before them and influences their interpretation of subsequent and unrelated events. But how does watching an event involving stirring and lifting spoons influence infants' interpretation of an occlusion event involving balls? The current results suggest that even though the formation of categorical event representations is relatively constrained (e.g., the actions must be functionally relevant and infants must see at least 2 or 3 exemplar pairs) the effect of engaging in this process is quite general. Once sensitivity to color, or pattern, information is increased it carries over into other events linked closely in space and time. Additional research will be necessary to determine whether there are some limitations to the kinds of events for which color and pattern priming will apply and whether these effects are short- or long-term. Regardless of the outcome of future research, it is clear that there is a certain degree of plasticity in the type of information that infants include in their representations of occluded objects and that the type of information to which infants attend is determined, at least in part, by recent experiences.

All of our research to date has focused on linking color to object function because we hypothesized that object function is a pervasive, salient, and meaningful source of information. We suspect, however, that there are other object properties, such as the mechanical or causal properties of objects, to which infants are equally sensitive. For example, we suspect that infants find mechanical events salient and that viewing color-mechanics pairings (i.e., green objects are self-propelled and red objects are inert) would prime infants to attend to color differences in a subsequent individuation task. In other words, we propose that infants can form categorical event representations under a wide variety of situations, as long as infants can (a) identify a salient source of information to which they can link less meaningful information and (b) detect commonalities across exemplars.

6.4. Other examples of priming in infants

The color–function priming results join a growing body of literature demonstrating that infants can be led, through select experiences, to attend to information to which they typically do not attend (Baillargeon, 2004; Baillargeon & Wang, 2002; Needham, 2000; Needham et al., 2002; Wang & Baillargeon, 2005; Wilcox et al., 2007). A closely related example is that of pattern-priming in younger infants. Recall that infants first spontaneously use pattern differences to individuate objects at 7.5 months (Wilcox, 1999). However, infants as young as 4.5 months can be primed to attend to pattern differences using the pound–pour procedure (Wilcox & Chapa, 2004).

There are also other mechanisms by which infants can be primed to attend to color and pattern information in an individuation task. Recently, Wilcox et al. (2007) examined the extent to which simultaneous visual and tactile exploration of objects, prior to an individuation task, would lead infants to attend to color information. The rationale behind this approach is that once infants sit up unsupported and begin to reach for and actively manipulate objects, around 5 months of age (Rochat, 1989; Rochat & Goubet, 1995; Streri, 1991/1993), 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, as well as to link information from one modality to another. There is evidence that multisensory experiences lead to the formation of multimodal object representations that are more rich and robust than unimodal representations (Bahrick & Lickliter, 2002; Bahrick, Lickliter, & Flom, 2004; Hernandez-Reif & Bahrick, 2001; Slater, Quinn, Brown, & Hayes, 1999).

On the basis of this reasoning, Wilcox et al. (2007) allowed 10.5-month-olds, who do not spontaneously use color information to individuate objects, multisensory experiences with the test objects prior to an individuation task. Infants were tested in one of two conditions: multisensory or unisensory exploration. In the *multisensory exploration* condition, infants were presented with two pre-exposure trials. In the first pre-exposure trial, infants were allowed to look at and touch the green ball for 60 seconds. In the second pre-exposure trial, the same procedure was used with the red ball. The balls were presented successively, never together. Following the pre-exposure trials, infants saw the narrow- or wide-screen green ball–red ball test event. The infants in the *unisensory exploration* condition were tested using the same procedure except that the infants were allowed to look at but not touch the balls during the pre-exposure trials. The infants in the multisensory exploration condition successfully individuated the green and the red ball (i.e., they looked reliably longer at the narrow- than wide-screen test event), whereas the infants in the unisensory exploration condition failed to do so (i.e., they looked about equally at the two test events). These data suggest that combined visual and tactile exploration of the objects, but not visual exploration alone, increases infants' sensitivity to color information in the test trials. Similar results have been obtained in pattern experiments. Infants aged 6.5- and 5.5-months can be primed to attend to pattern differences in an individuation task if they are allowed multisensory exploration of the dotted and the striped ball, one at a time, prior to the test trials (Woods & Wilcox, 2006b). Wilcox et al. (2007) proposed that multisensory experience with the balls allows infants to form an amodal object representation into which infants can more easily integrate color information. Hence, the mechanisms involved in multisensory priming are quite different from those involved in feature–function priming. Whereas feature–function priming renders color and pattern more salient by linking color or pattern to an object property to which infants are already sensitive, multisensory priming relies on a sensory integration mechanism to enhance sensitivity to color and pattern differences. Together, these results suggest that there may be a wide array of cognitive and perceptual mechanisms that can support color and pattern priming in infants.

A striking demonstration of priming outside of object individuation is one that involves infants' use of height information (Wang & Baillargeon, 2005). There is evidence that by 3.5 months infants attend to height information when interpreting occlusion events (Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987). 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. In these experiments, 8-month-olds saw an event in which a short cover was placed in front of a short or a tall object (occlusion event). The short but not the tall object was occluded by the short cover. Next, the infants saw the short cover lowered over the short or the tall object until it became fully hidden (covering event). After viewing the occlusion event, the infants looked reliably longer at the tall- than the short-object covering event. In a control condition, where the short cover was moved forward but did not occlude the short or tall object in the first event, the infants looked equally at the tall- and short-object covering event. These results suggest 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). They also provide converging evidence for the idea that infants' object representations are relatively flexible and that sensitivities are dependent, at least in part, on infants' recent experiences.

6.5. *Infants' sensitivity to color information: A caveat*

All of the individuation research that we have discussed here, and that we have carried out in our lab, has been conducted using artifacts (e.g., balls, boxes, cups). We recognize this limitation and acknowledge that the developmental hierarchy favoring form over surface features that we have observed in our studies may not generalize to all types of objects. Some developmental psychologists have proposed that humans possess distinct domains of knowledge, such as artifacts and natural kinds, and that the type of information to which infants and children are sensitive, and they way in which they process this information, varies by domain (Gelman & Coley, 1990; Hirschfeld & Gelman, 1994; Keil, 1989; Leslie, 1994). A great deal of evidence has accumulated, in both human and non-human primates, in support of this proposal. For example, there is evidence that when an object is an artifact 2- and 3-year-olds are more likely to extend labels on the basis of shape; when the object is an animate object, they are more likely to extend labels on the basis of shape and texture (Booth & Waxman, 2002a; Booth, Waxman, & Huang, 2005). Likewise, non-human primates are more likely to identify and categorize artifacts on the basis of form than surface features (Hauser, Pearson, & Seelig, 2002; Santos, Hauser, & Spelke, 2001; Santos, Hauser, & Spelke, 2002a; Santos, Miller, & Hauser, 2003; Santos, Mahajan, & Barnes, 2005). In contrast, when categorizing and individuating food, non-human primates are more likely to attend to color than shape differences (Santos et al., 2001; Santos et al., 2002a; Santos, Sulkowski, Spaegen, & Hauser, 2002b). Interestingly, complimentary results have been reported with young children. Macario (1991) reported that 2- to 4-year-olds recognize that color is important to classifying food items, and are more likely to use color than shape to categorize novel objects when they think the objects are something to eat. Together, these data suggest that caution is warranted when interpreting the developmental hierarchy favoring form over surface features. Further research is needed to determine the extent to which different hierarchies exist when infants are reasoning about food, animate objects, and other natural kinds.

7. Concluding remarks

The results obtained in the present experiments shed light on the way in which infants attempt to make sense of a plethora of incoming information. One way is to link information of which they are unsure—that they have yet to identify as relevant to understanding physical events—to information to which they are already sensitive. The outcome of this process can have profound effects on the type of information to which infants attend and can promote learning about objects as individual entities. The present results also demonstrate flexibility in the type of information infants include in their object representations and shed light on factors that contribute to changes in early object knowledge. For example, sensitivities are dependent, at least to some extent, on infants' recent experiences. We are confident that further investigation using the color–function priming procedure and its variants will 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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