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6

Object Individuation in Infancy

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One of the most basic cognitive capacities people possess is the ability to represent the world in terms of distinct objects. The outcome of this process determines how people think about and act on those objects. The problem of *object individuation*—determining the number of separate and distinct entities present in an event—has long been a topic of interest to psychologists. This topic has recently received a great deal of attention from infant researchers (Aguiar & Baillargeon, in press; Leslie, Xu, Tremoulet, & Scholl, 1998; Spelke, Kestenbaum, Simons, & Wein, 1995; Tremoulet, Leslie, & Hall, 20001; Wilcox, 1999b; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Schweinle, in press; Xu & Carey, 1996). Much of this research has focused on the kind of information that infants use to individuate objects in occlusion events.

Most investigators would agree that *spatiotemporal* information is fundamental to the individuation process. From a very early age, infants interpret spatiotemporal discontinuities as signaling the presence of distinct objects. For example, when shown an event in which an object disappears behind the first of two spatially separate screens, and then emerges from behind the second screen without appearing between the two screens, infants as young as 3.5 months are led by the discontinuity in path to conclude that two distinct objects are involved in the event (Aguiar & Baillargeon, in press; Spelke, Kestenbaum, et al., 1995; see Xu & Carey, 1996, for older infants). Likewise, when presented with an event in which an object disappears behind one edge of a wide screen and then reappears immediately at the other edge, 3.5-month-olds take the discontinuity in speed to signal the presence of two objects (Wilcox & Schweinle, 2001).

In contrast, there has been less agreement about the role that *featural* information plays in the individuation process. Whereas some researchers have claimed that young infants are incapable of using featural information to individuate objects until the end of the first year of life (Xu & Carey, 1996; see also Xu, Carey, & Welch, 1999), others have suggested that this ability emerges much earlier, by at least 4.5 months of age (Wilcox, 1999b; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Schweinle, in press; see also Needham, Baillargeon, & Kaufman, 1997, and Needham & Baillargeon, 2000). We begin this chapter with a review of the negative evidence and offer an alternative interpretation of these results, along with the experiments that support this interpretation. We then turn to experiments that have systematically investigated infants' changing sensitivity to object features during the first year of life. Next we consider the distinction between object individuation and object identification (Leslie et al., 1998) and review evidence that supports this distinction. Finally, we reflect on what these results, as a whole, tell us about the nature and content of the early representational system.

INFANTS' USE OF FEATURAL INFORMATION TO INDIVIDUATE OBJECTS

Negative Findings

Xu and Carey (1996) examined 12- and 10-month-olds' ability to use featural information to reason about the number of objects present in an occlusion event. In their experiments, infants were first presented with baseline trials in which they saw either one object (e.g., a bunny) or two objects (e.g., a bunny and a basket). Infants next saw test trials. At the beginning of each test trial, one object (e.g., a duck) moved from behind the left edge of a wide screen and returned; a different object (e.g., a ball) then moved from behind the right edge of the screen and returned. The process was repeated until infants saw multiple emergences of each object. At the end of each test trial the screen was removed to reveal either one object (e.g., a duck) or two objects (e.g., a duck and a ball).

The 12-month-olds looked reliably longer at the two-objects display than at the one-object display during the baseline trials but tended to look equally at the two displays during the test trials. These test results suggested that (a) the infants inferred, on the basis of the featural differences between the objects that emerged on each side of the screen, that two objects were present; (b) the infants were surprised when the screen was removed to reveal the one-object test display; and (c) the infants' surprise at the one-object test display, combined with their intrinsic preference for the two-objects test display (a preference suggested by the baseline data), resulted in equal looking times at the two test displays.

In contrast to the 12-month-olds, the 10-month-olds looked reliably longer at the two-objects display than at the one-object display during both the baseline and test trials. Xu and Carey (1996) took these results to suggest that (a) the 10-month-olds were not able to use the featural information available in each test trial to infer how many objects were involved in the trial; (b) the infants found neither the one-object nor the two-objects test display surprising; and (c) the infants' test responses reflected only their intrinsic preference for the two-objects test display (a preference suggested by the baseline data).

The results obtained with the 10-month-olds were replicated in three additional experiments conducted with slight procedural modifications (Xu & Carey, 1996). The infants consistently failed to individuate the objects on the basis of the featural differences between them. The 10-month-olds gave evidence that they recognized that two distinct objects were present only when tested in a condition in which they were shown the two objects simultaneously at the start of the test trials—in other words, only when they were able to use spatiotemporal information to individuate the objects.

On the basis of these results, Xu and Carey (1996) concluded that the ability to use featural information to individuate objects emerges between 10 and 12 months of age. More generally, they speculated that the ability to use featural differences to set up representations of numerically distinct objects is linked to the development of specific object concepts and that infants 10 months and younger lack such concepts. (It would be difficult to conceive how an infant who possessed such concepts could fail to represent objects with the features "red, spherical, and smooth" and "yellow, duck-shaped, and fuzzy" as distinct objects.) Furthermore, they hypothesized that language acquisition—more specifically, word learning—plays an important role in the development of this ability at the end of the first year. Until this time, however, infants represent objects simply as solid, bounded entities without reference to property or kind information.

It is important to make clear that the results obtained by Xu and Carey (1996) are quite robust and have been replicated by other investigators (Leslie et al., 1998; Wilcox & Baillargeon, 1998a). For example, Wilcox and Baillargeon (1998a) tested 11.5- and 9.5-month-olds using a task patterned after the one Xu and Carey (1996) used. The infants were assigned to a ball–box or a ball–ball condition (see Fig. 6.1). The infants in the ball–box

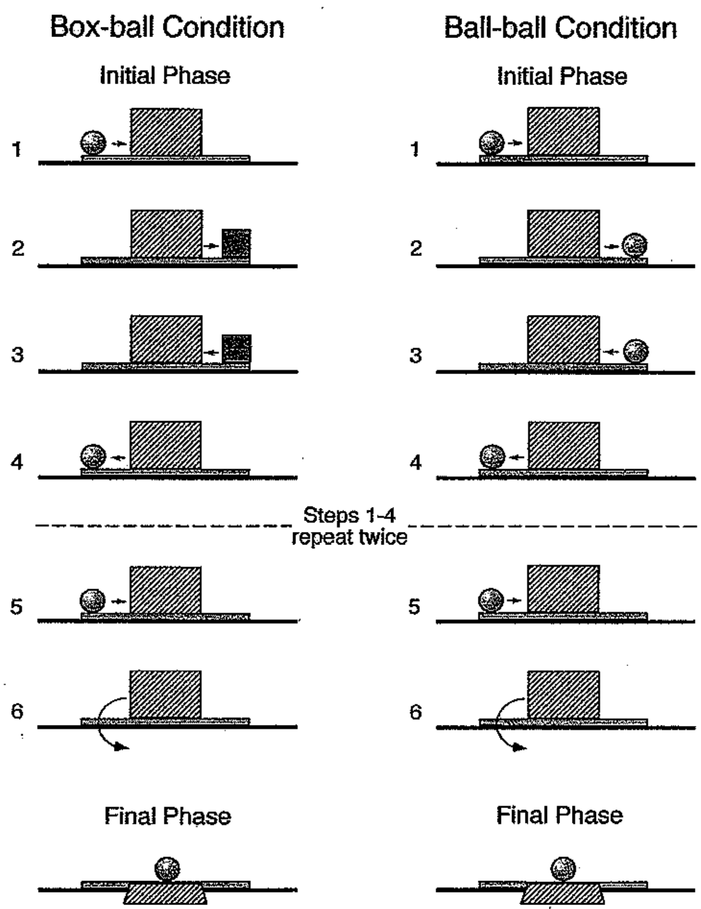

FIG. 6.1. Ball–box and ball–ball test events in Wilcox and Baillargeon (1998a).

condition saw a test event composed of an initial and final phase. During the initial phase of the test event the infants saw a ball move behind the left edge of a wide screen; after a brief interval, a box appeared at the screen's right edge. Next, the box returned behind the screen, and the ball returned to its initial position to the left of the screen. The entire ball–box sequence was then repeated a second time. Finally, the ball moved behind the screen one last time, and the screen was lowered to the apparatus floor, marking the end of the initial phase. During the final phase of the test event the infants saw the ball resting alone behind the screen. (To circumvent infants' baseline preference for displays composed of two different objects over displays containing a single object, only one test display was used, and this display contained a single object.) The infants in the ball–ball condition saw a similar test event, except that a ball, rather than a box, emerged to the right of the screen.

The 11.5-month-olds in the ball–box condition looked reliably longer at the final one-ball display than did the infants in the ball–ball condition. These and control results suggested that the infants in the ball–box condition (a) were led by the featural differences between the ball and box to conclude that they were two distinct objects, and (b) detected the discrepancy between their representation of the initial phase of the event and the display shown in the final phase of the event, and hence (c) responded with prolonged looking to the one-ball display. In contrast, the infants in the ball–ball condition (a) assumed, on the basis of the featural similarities between the balls seen on either side of the screen, that they were one and the same ball and (b) found the one-ball display consistent with their representation of the ball–ball event. In contrast, the 9.5-month-olds in the two conditions looked about equally during the final phase of the test event, as though they had failed to detect the incongruity between their representation of the initial ball–box event and the final one-ball display.

Why did the 9.5-month-olds fail to detect the discrepancy between the initial and final phases of the test event? One interpretation of these results, and the one in line with Xu and Carey's (1996) interpretation, is that the 9.5-month-olds failed to use the featural differences between the ball and the box to draw conclusions about the number of objects present in the initial phase of the test event. If the infants had judged that two separate and distinct objects, a ball and a box, were present in the event, then they should have been surprised to see only one object, the ball, when the screen was lowered. However, Wilcox and Baillargeon (1998a) proposed an alternative explanation for the negative results obtained with the younger infants. We outline this explanation in the next section.

An Alternative Interpretation of the Negative Findings

It is possible that the 10-month-olds tested by Xu and Carey (1996) and the 9.5-month-olds tested by Wilcox and Baillargeon (1998a) failed not because they were unable to individuate the objects but because the task was too challenging in other respects. Two types of tasks have been used to assess object individuation in infancy: event mapping and event monitoring (Wilcox & Baillargeon, 1998a). These tasks differ in the information-processing demands they impose.

In a typical *event-mapping* task infants see an event in which one object or two objects emerge successively to each side of a screen, the screen is removed, and then infants see a display containing either one object or two objects. To succeed on an event-mapping task, infants must set up a representation of the first event and evaluate its progress (i.e., judge whether the objects' movements and interactions are consistent with their existing knowledge). When the screen is removed, infants must set up a new representation for the second event and then evaluate its progress. Finally, in an attempt to make sense of these two independent situations, infants must form a link between them. The linking together, or mapping, of event representations requires that infants (a) retrieve their representation of the first event, (b) compare it to their representation of the second event, and (c) judge whether the two events are consistent.

In contrast, in an *event-monitoring* task infants see only one event, usually an occlusion event, involving either one or two objects. As infants observe the event, they must monitor whether successive portions of the event are consistent. In general, infants are more likely to demonstrate successful performance when they are tested with an event-monitoring than an event-mapping task (Aguiar & Baillargeon, in press; Hespos, 2000; Leslie et al., 1998; Spelke, Kestenbaum, et al., 1995; Wilcox, 1999b; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Schweinle, 2001; Wilcox & Schweinle, in press; Xu & Carey, 1996), presumably because it is easier for infants to monitor the internal consistency of a single ongoing event than to map one event representation onto another. It is not difficult to see how event monitoring, which involves one processing step, would be less demanding than event mapping, which involves multiple processing steps.

The task used by Xu and Carey (1996), and then by Wilcox and Baillargeon (1998a), was an event-mapping task. At the start of each test trial, infants saw an event in which featurally distinct objects were seen successively to each side of the screen, the screen was removed, and then infants saw one object or two objects resting on the platform. The 10- and 9.5-month-olds' failure to respond correctly to the test trials may reflect their inability to complete the mapping process: The infants could not judge whether the objects seen in the first part of the test trial mapped onto the objects seen in the second part. Implicit in this interpretation of the results is that the infants successfully individuated the objects, but they were simply able to reveal this ability within the context of an event-mapping task.

This analysis raises two broad questions: (a) What makes a task an event-mapping task? and (b) what part of the process, in particular, is so difficult for young infants? The answers to these questions rests on two main assumptions. The first assumption is that the infants viewed the first and second parts of the test trial as two distinct situations rather than as one continuous situation. On what basis did they do so? There is evidence that infants group physical events into distinct categories (i.e., occlusion, support, or containment events), on the basis of the spatial and mechanical relations between the objects involved. Infants then learn and reason about the world in terms of selected categories (Baillargeon, 1995, 1998;

Baillargeon, Kotovsky, & Needham, 1995; Hespos & Baillargeon, 2001). It is likely that the infants categorized the first situation, in which the objects moved back and forth behind the screen, as one of occlusion. When the screen was removed, infants assigned the next situation, in which the objects rested on the platform, to a novel category. For lack of a better term, we refer to this as a *no-occlusion situation*. Hence, instead of viewing the screen's removal as simply a change in an ongoing situation, infants viewed it as marking the start of a separate and distinct physical situation. The recategorization process prompted infants to set up, or initiate, a new event representation.

The second assumption is that, just as infants are motivated to monitor changes within any one physical situation, infants also seek to keep track of changes across situations. This allows infants to make sense of the world as it plays out before them. Keeping track of the world across distinct events is not an easy task, however. The attempt to link two successive representations means retrieving the first event, identifying the objects in that event (at least their numerical identity), aligning those objects with the objects in the second event, and then judging whether the two events are consistent. Wilcox and Baillargeon (1998a) argued that the retrieval-and-comparison process taxes infants' memory and information-processing capacities, especially when the event to be mapped is more complex (e.g., involves multiple objects, the objects move on more complicated trajectories, or both). In other words, the heavier the burden that is placed on infants' processing abilities, the more likely it is that infants will be unable to judge whether two events are compatible.

Consider again the event-mapping tasks used by Xu and Carey (1996) and Wilcox and Baillargeon (1998a). In the initial phase of each test trial the objects emerged multiple times to each side of the screen, reversing direction each time to return behind the screen. The repeating nature of the event, which included multiple object reversals and occluded trajectories, resulted in a relatively lengthy and complex event. Infants' mapping of events like these can be accomplished in one of two ways: (a) retrieve and scan the entire event to determine what objects were involved in the event or (b) compose a summary representation[1] of the event that contains only the basic elements of the event (i.e., a box to one side of the screen and a ball to the other) and then map those elements onto the second event.

[1]In our current way of thinking, there are at least two kinds of summary representations. One is a literal "outline" of an event, which is created when infants successfully extract the simple, or spatial, structure of an event. This is the kind of summary representation on which we focus in this chapter. The other kind of summary representation is more conceptual. Xu and Carey (1996) reported preliminary data suggesting that the acquisition of object labels facilitates the mapping process. Verbal labels may allow infants to easily summarize a visual event and provide a conceptual link to objects from previous representations.

Event Mapping: Testing Assumptions

The approach just outlined makes several testable predictions about when infants should succeed on event-mapping tasks. In the following sections we describe three of these predictions and the experiments that were conducted to test them.

Test of Assumption 1: A Change in Event Category. The first assumption, that event categorization leads infants to initiate a new representation, makes a very straightforward prediction. If the event category did not change with the lowering of the screen—if the initial and final phases of the test event were from the same event category—then infants should view the test event as one continuous physical situation rather than as two discrete situations. If 9.5-month-olds needed to reason about only a single continuous event, rather than about two distinct events, then they should be more likely to succeed. This prediction was recently tested with a two-phase task in which the initial and final phases of the test event both involved occlusion situations (Chapa & Wilcox, in press; see also Hespos, 2000). During the initial phase of the test event (see Fig. 6.2) 9.5-month-olds saw a box (box–ball condition) or a ball (ball–ball condition) emerge from behind the left side of a screen and return; next, a ball emerged from behind the right side of the screen and returned. The infants saw only one event cycle (i.e., one object reversal to each side of the screen). The center portion of the screen was then removed so that a frame, approximately 2.5 cm wide all the way around, remained standing. During the final phase of the test event infants saw a single ball resting at the center of the platform, behind the frame. For half of the infants, a transparent pane was placed in the frame (transparent-pane condition); for the other infants, the frame was empty (no-pane condition). If the infants in the transparent-pane condition (a) view the test event as involving only one kind of physical situation, an occlusion situation with first an opaque and then a transparent occluder, and (b) are able to monitor the internal consistency of the test event as it unfolds before them, then the box–ball infants should find the one-ball display unexpected. Furthermore, if the infants in the no-pane condition (a) view the test event as composed of two distinct physical situations, an occlusion situation followed by a no-occlusion situation, as one would expect, and (b) have difficulty mapping the objects from the box–ball event onto the one-ball display, then the box–ball and ball–ball infants should look about equally during the final phase.

The results confirmed these predictions. In the transparent-pane condition the infants who saw the box–ball event looked reliably longer at the one-ball display than did the infants who saw the ball–ball event. In contrast, in the no pane condition the infants who saw the box–ball and

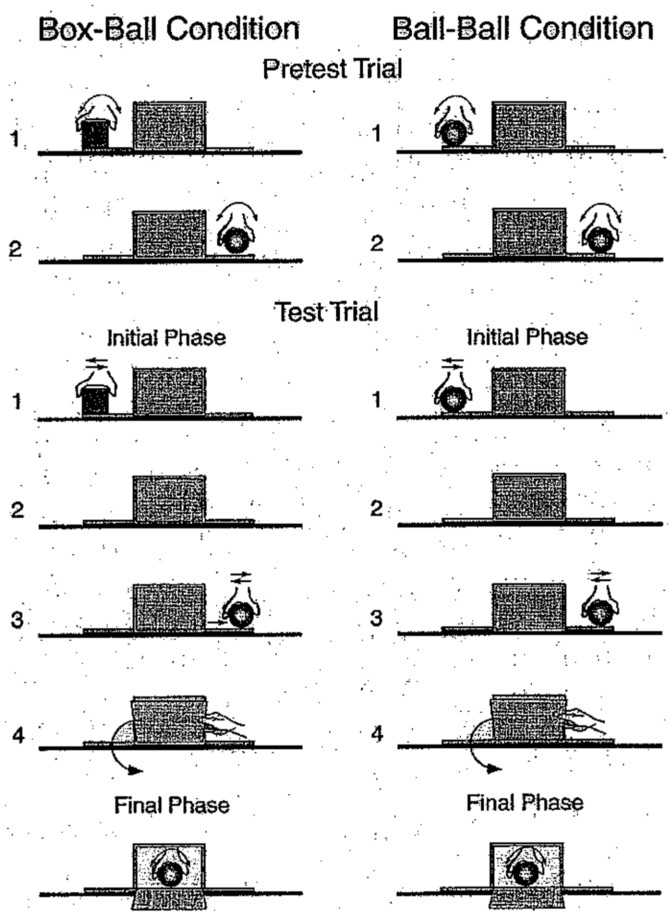

FIG. 6.2. Box–ball and ball–ball test events in Wilcox and Chapa (in press). In the transparent-pane condition the frame seen in the final phase held a transparent pane; in the no-pane condition the frame was empty.

ball–ball events looked about equally at the final display. (Positive results were also obtained in a condition in which the transparent pane contained dots.) These results suggest that the infants (a) categorized the display involving the transparent occluder as the same sort of physical situation as the event involving the opaque occluder and (b) found it easier to demonstrate successful performance when they needed to reason about only one physical situation than when they were required to map categorically distinct situations. It is clear that the infants were more adept at evaluating the one-ball display when it was embedded within a single event than when they had to compare the one-ball display to their representation of a previous event.

The transparency results are exciting, not only because they provide insight into the processes in which infants engage as they attempt to organize and interpret the multitude of events that they encounter daily, but also because they shed light on how infants go about identifying events as belonging to the occlusion event category. Infants apparently find that the relation "behind something," or the inference "cannot be reached directly," is as important as the relation "out of view." These results are consistent with other recent research that has investigated infants' understanding of transparent occluders (Johnson & Aslin, 2000; see Luo, 2001, for research on infants' understanding of transparent occluders and containers). Further investigation is needed to determine how infants' notion of occlusion might change during the first year of life.

Test of Assumption 2: Simplifying the Event. The second assumption, that the retrieval and comparison process is difficult for infants, particularly when the event to be mapped is complex, makes several testable predictions. One is that infants younger than 11.5 months might succeed at an event-mapping task if the occlusion event were made extremely simple and brief, so as to reduce the burden associated with retrieving and scanning the event. To examine whether infants would demonstrate success if the occlusion event were simplified, Wilcox and Baillargeon (1998a) tested 9-month-olds in one of two experimental conditions: box–ball or ball–ball (Fig. 6.3). In the initial phase of the test event infants saw either a red box (box–ball condition) or a green ball (ball–ball condition) disappear behind the left edge of a wide screen and a green ball appear from behind the right edge; then the screen was lowered. In the final phase of the test event infants saw only the ball to the right of the screen (the area behind the screen was empty). Infants in a control experiment saw the same events except that when the screen was lowered a second, slightly shorter screen was revealed (Fig. 6.4). The second screen was sufficiently tall to hide the box, allowing for the presence of the box behind the screen. The infants in the experimental box–ball condition looked reliably longer during the final phase of the test event than did the infants in the experimental ball–ball condition. In contrast, the infants in the control box–ball and ball–ball conditions looked about equally at the one-ball display (and these looking times were similar to those of the infants in the experimental ball–ball condition). These results suggest that the infants in the box–ball condition expected two objects to be revealed when the screen was lowered and were surprised when this expectation was violated. Further data indicate that the positive result obtained in this event-mapping task was extremely fragile: When the event sequence shown to the experimental box–ball infants

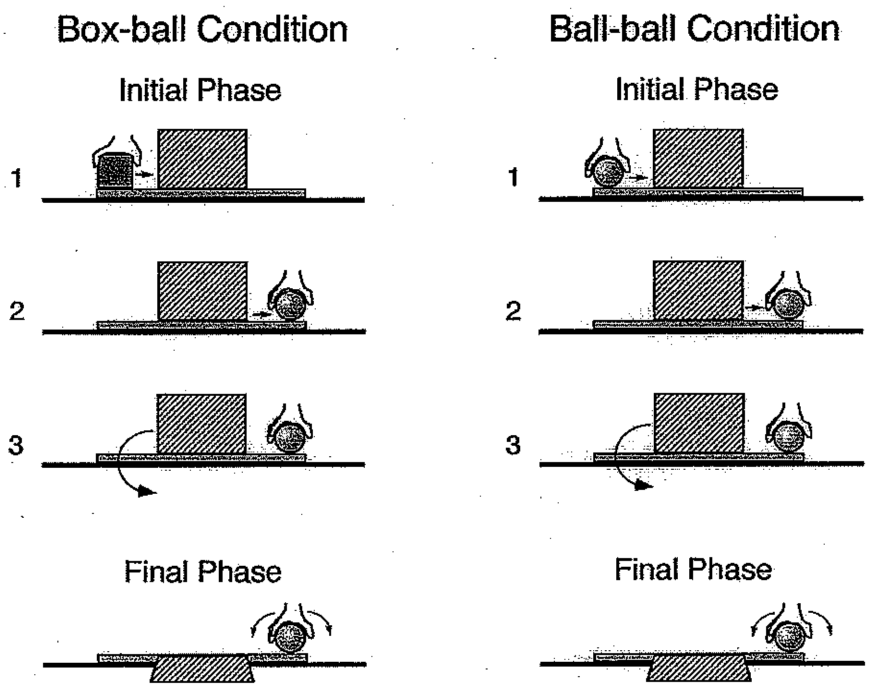

FIG. 6.3. Experimental box–ball and ball–ball test events in Wilcox and Baillargeon (1998a).

was made slightly longer—the box sat behind the screen at the start of the trial and first moved to the left, into view, before proceeding to the right, as before—the infants no longer responded with prolonged looking. Adding a single reversal to the box's motion at the start of the event sequence was enough to impair the infants' ability to judge whether the objects involved in the occlusion situation correctly mapped onto those revealed in the no-occlusion situation.

Given that an event-mapping task is made substantially easier when the objects follow a single trajectory, we wondered whether infants younger than 9 months would also evidence at least some measure of success. Wilcox and Schweinle (in press) tested 7.5-, 5.5-, and 4.5-month-olds using a simplified event-mapping task identical to the one just described (Wilcox & Baillargeon, 1998a), with one exception: The box and ball were replaced with an egg and a column (see Fig. 6.5). In the initial phase of the test event infants saw either an egg (egg–column condition) or a column (column–column condition) move behind the left edge of a wide screen and a

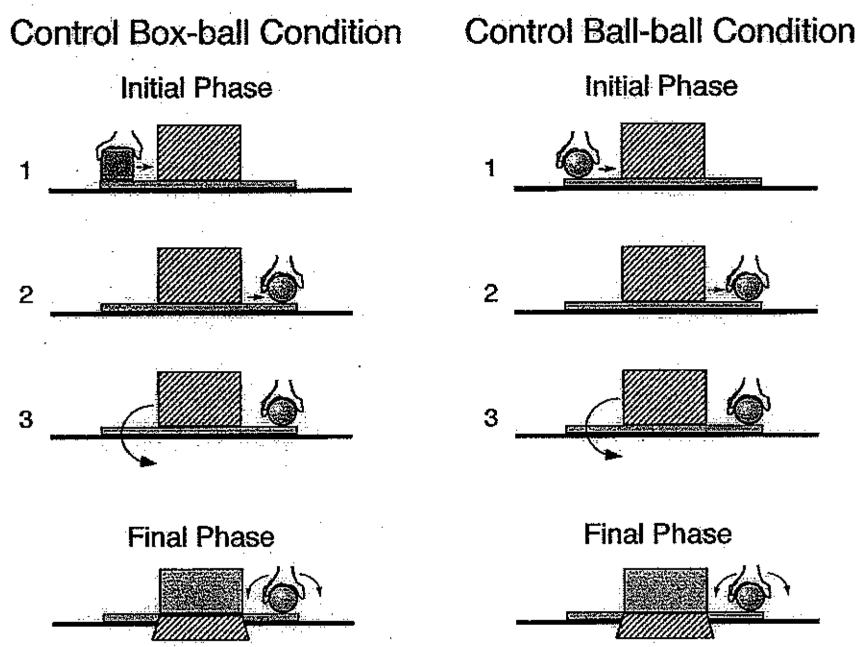

FIG. 6.4. Control box–ball and ball–ball test events in Wilcox and Baillargeon (1998a).

column appear at the right edge; the screen was then lowered. In the final phase of the test event the infants saw a single column to the right of the screen. The 7.5- and 5.5-month-olds in the egg–column condition looked reliably longer at the final one-column display, suggesting that the infants had successfully compared their representation of the initial phase of the test event to the one column before them. In contrast, the 4.5-month-olds in the two conditions looked about equally at the one-column display, suggesting that these younger infants did not detect the discrepancy between the initial and final phases of the egg–column test event.[2]

A Further Test of Assumption 2: Making Clearer the Spatial Structures of Events. The second assumption also predicts that the mapping process would be facilitated if infants were given information to help them

[2]The negative results obtained with the 4.5-month-olds could be interpreted in one of two ways: (a) The infants failed to individuate the objects or (b) the infants were unable to complete the mapping process. Experiments conducted with event-monitoring tasks (Wilcox, 1999b: Wilcox & Baillargeon, 1998b) have yielded positive results with 4.5-month-olds, suggesting that the latter interpretation is correct.

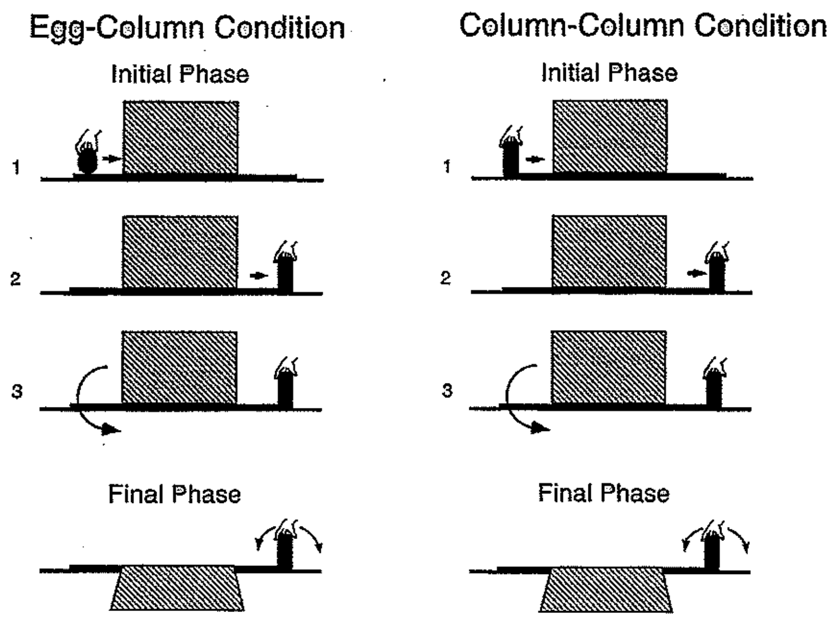

FIG. 6.5. Egg–column and column–column test events in Wilcox and Schweinle (in press).

compose a summary representation of the test event. To examine this hypothesis, Wilcox (1999a) presented 7.5-month-olds with a two-phase test event. In the initial phase of the test event a box (box–ball condition) or a ball (ball–ball condition) emerged from behind the left side of a screen and then returned; next, a ball emerged from behind the right side of the screen and returned (Fig. 6.6). The entire event cycle was repeated, and then the screen was lowered. In the final phase of the test event infants saw a single ball on the platform. Hence, the infants in this experiment, like the 11.5- and 9.5-month-olds tested by Wilcox and Baillargeon (1998a), saw an occlusion event in which the objects underwent two reversals to each side of the screen followed by a no-occlusion event containing a single ball. Where this experiment differs from that of Wilcox and Baillargeon (1998a) is in what the infants saw immediately prior to the test trials.

In Wilcox and Baillargeon's (1998a) experiment the infants were presented with two familiarization trials before they were presented with the test trials. In the familiarization trials the infants saw the same event as they saw in test trials, with one exception: When the screen was lowered a second, shorter screen occluded trhe center portion of the platform. The purpose of the familiarization trials was to acquaint the infants with the event

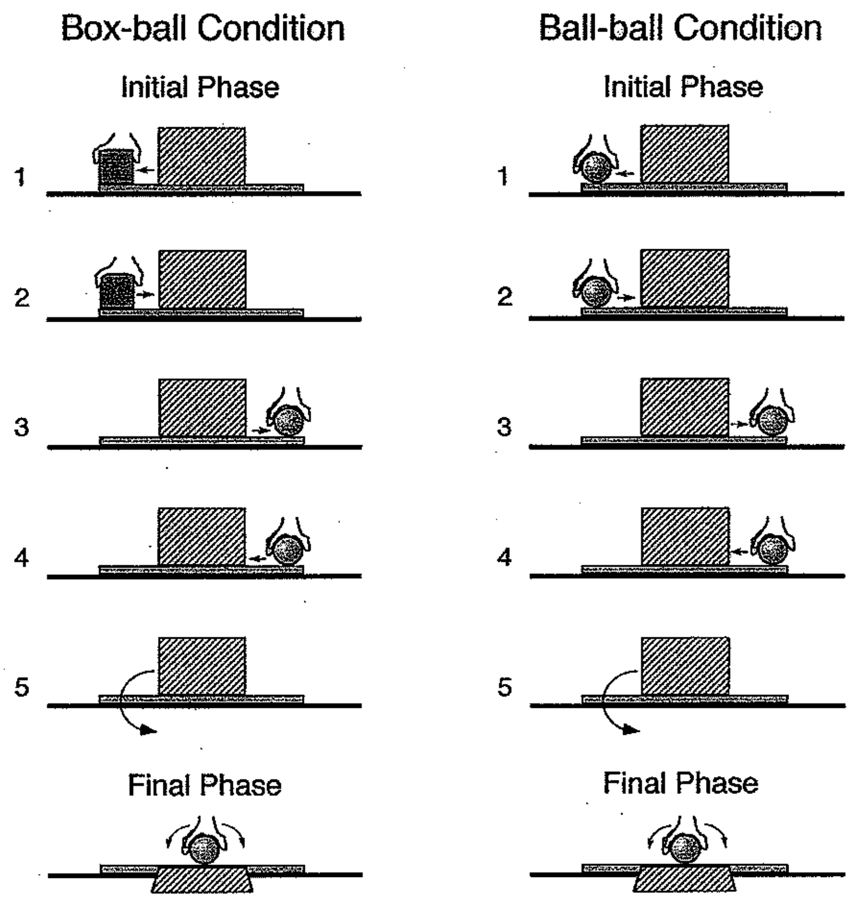

FIG. 6.6. Box–ball and ball–ball test events in Wilcox (1999a). Steps 1–5 were seen twice before the screen was lowered.

they would see in the test trials without assessing their interpretation of the event objects (i.e., did the event involve one object or two objects?). In Wilcox's (1999a) experiment infants saw pretest trials of a different ilk. Rather than viewing the entire event sequence on both familiarization trials, the infants saw only a portion of the event sequence on each trial. In the first familiarization trial the box (box–ball condition) or the ball (ball–ball condition) started behind the screen, emerged to the left of the screen, and then returned (i.e., Steps 1–2 in Fig. 6.6). In the second familiarization trial the ball started behind the screen, emerged to the right of the screen, and then returned (i.e., Steps 3–4 in Fig. 6.6). Hence, infants saw the simple, or what we refer to as the *spatial,* structure of the event one piece at a time—first a box moving to the left of the screen and then a ball moving to the right—prior to the test event.

A different pattern of results was obtained for the boys than for the girls. For the boys, the infants in the box–ball condition looked longer than those in the ball–ball condition, as if they had used the "outline" provided in the object-display trials to help them organize and structure the event seen in the test trials. In contrast, the girls in the two conditions looked about equally at the final one-ball display, as if they had failed, despite seeing the event outline, to extract the simple structure of the box–ball event. Follow-up experiments indicated, however, that girls succeeded if they were given additional exposure to each of the objects' trajectories. If the object emerged twice to the side of the screen in each object-display trial, making even more clear the path that each object would follow, the girls successfully mapped the box–ball event onto the one-ball display. Apparently, 7.5-month-old girls find it more difficult to extract the simple structure of occlusion events; however, once the structure has been identified they can successfully compare it to the structure of a subsequent event.

Positive Findings Obtained With an Event-Monitoring Task

In recent investigations the event-mapping results just described have been confirmed and extended with an event-monitoring task (Wilcox, 1999b; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Chapa, 2001). Recall that in an event-monitoring task infants see only one event (e.g., an occlusion event) and must monitor the internal consistency of that event. In one event-monitoring task, Wilcox and her colleagues have examined infants' ability to judge whether two objects could fit behind a screen that was either too narrow or sufficiently wide to hide both objects simultaneously.

The Wide- and Narrow-Screen Results. In the initial event-monitoring experiments (Wilcox & Baillargeon, 1998b), 7.5- and 9.5-month-olds saw a test event in which a green ball moved behind the left edge of a screen and, after a brief interval, a red box appeared at the right edge (see Fig. 6.7). The red box then reversed direction to return behind the screen, and the green ball emerged and returned to its starting position. The entire ball–box sequence was repeated until the end of the trial. For half the infants, the test screen was sufficiently wide to occlude the ball and box simultaneously (wide-screen condition); for the other infants, the test screen was too narrow to occlude both objects at the same time (narrow-screen condition). Data obtained with adult observers indicated that the narrow-screen violation was quite salient. Adults correctly judged that both objects could not fit, side by

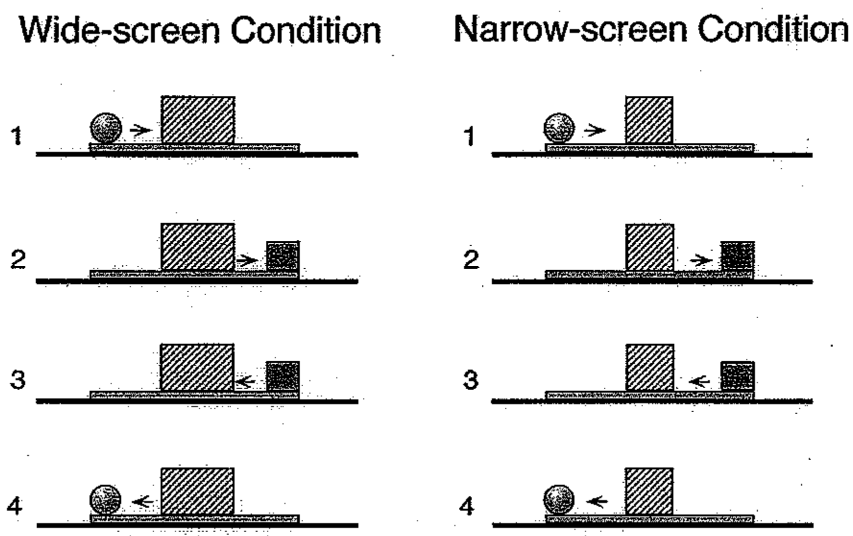

FIG. 6.7. Experimental wide- and narrow-screen test events in Wilcox and Baillargeon (1998a).

side, behind the narrow screen and, in fact, overestimated the amount of space that the two objects occupied (Wilcox & Baillargeon, 1998a). The infants in the narrow-screen condition looked reliably longer at the test event than did the infants in the wide-screen condition. This result suggests that the 7.5- and 9.5-month-olds: (a) were led by the featural differences between the ball and box to view them as two distinct objects; (b) correctly judged that the ball and box could be occluded simultaneously by the wide screen but not the narrow screen; and (c) were puzzled or intrigued when this last expectation was violated. These conclusions were supported by a control experiment in which the ball and box were replaced with a smaller ball and box that could both fit behind either screen. The infants in the control wide- and narrow-screen conditions looked about equally at the test event, suggesting that they had correctly judged that the smaller ball and box could simultaneously be occluded by the wide or the narrow screen.

In another experiment, Wilcox and Baillargeon (1998b) used a similar procedure to test younger infants' interpretation of different- and same-features occlusion events. In this experiment, 7.5- and 4.5-month-olds were assigned to one of two conditions: ball–box or ball–ball. The infants in the ball–box condition (Fig.6. 8) saw the wide- or narrow-screen test event from Wilcox and Baillardeon (1998b; Fig. 6.7); the wide but not the narrow screen was sufficiently wide to hide the ball and the box simultaneously. The infants in the ball–ball condition saw a similar event except that a ball was seen to both sides of the wide or narrow screen. Both the 4.5- and 7.5-month-olds in the ball–box condition looked reliably longer at the test event when it was seen with the narrow screen than the wide screen, suggesting that the infants had used the featural differences to conclude that two distinct objects were present in the ball–box event and correctly judged that both objects could not simultaneously fit behind the narrow screen. In contrast, the infants in the ball–ball condition looked about equally at the narrow- and wide-screen test events, as if the infants had assumed that the balls seen to each side of the screen were one and the same object and recognized that the ball could fit behind either screen. Together, these results suggest that infants as young as 4.5 months interpret different- and same-features events in a manner consistent with their featural content. When different features are seen to each side of the screen, infants assume that two objects are involved in the event; when the same features are seen to each side of the screen, infants assume that only one object is present.

The Tunnel Effect as an Explanation for the Narrow-Screen Results. Recently, Xu and Carey (2000) offered an alternative explanation for infants' prolonged looking to the narrow-screen events that does not require infants to use featural information to individuate the objects. The logic of their accounts rests on a visual phenomenon called the *tunnel effect* (e.g., Burke, 1952; Michotte, Thinès, & Crabbé, 1964/1991). In experiments investigating the

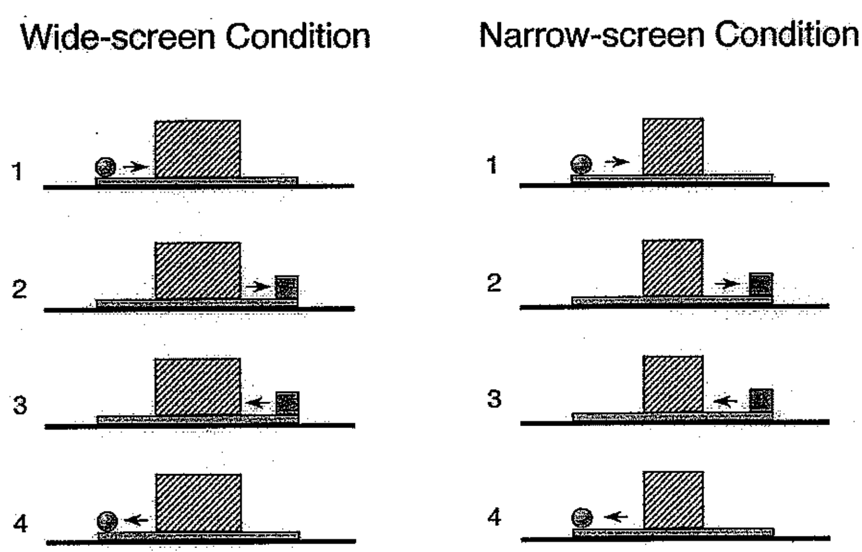

FIG. 6.8. Control wide- and narrow-screen test events in Wilcox and Baillargeon (1998a).

tunnel effect, adult observers view an event in which an object disappears behind one edge of an occluder and then reappears at the other edge. Under the right conditions (e.g., related to the width of the screen, the speed of motion, the time of occlusion, and the shape of the trajectory), adult observers perceive a single object moving at a uniform speed behind the occluder; they report "seeing" the object move behind the occluder. Many researchers have argued that the tunnel effect is an example of amodal completion: In the absence of physical stimulation, some portion of the stimulus or the event (in this case the object's path of motion) is "filled in."

Most pertinent to Xu and Carey's (2000) argument is that when the objects seen to each side of the occluder differ in their featural properties (i.e., shape, size, color), adults still interpret the event as involving a single object, an object that changed its appearance when behind the occluder (Burke, 1952; Michotte et al., 1964/1991). Xu and Carey (2000) suggested that the conditions of the narrow-screen event are the same as those that support amodal completion. According to this view, the infants in Wilcox and Baillargeon's (1998a, 1998b) experiments evidenced prolonged looking to the narrow-screen ball–box event because they: (a) assumed that the event involved a single object that moved back and forth behind the screen, (b) detected that the objects seen to each side of the screen differed in their featural composition, and (c) were puzzled that the object changed its featural properties when behind the screen.

There are several reasons, however, to doubt such an explanation. Two of the most convincing reasons are as follows. First, the conditions that are known to support the tunnel effect are not the same as those of the narrow-screen experiment. For example, to obtain the narrow-screen results, the width of the two objects, combined, must be greater than the width of the screen. Infants evidence prolonged looking to a narrow-screen event only when the screen is too narrow to hide both objects simultaneously (Wilcox, 1999b; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Chapa, 2001). If the width of one or both objects is decreased so that now both objects can fit behind the narrow screen at the same time (e.g., Wilcox & Baillargeon, 1998a, Experiments 3 and 6), infants are not surprised by the narrow-screen event. The "width factor," which is absolutely critical to obtaining the narrow-screen results, is not required to produce the tunnel effect. More specifically, the tunnel effect can be obtained with featurally distinct objects regardless of whether the screen is too narrow, or sufficiently wide, to hide both objects simultaneously (Burke, 1952; Coen-Gelders, 1961, cited in Michote et al., 1991). Second, Xu and Carey's (2000) account assumes that the infants in the wide-screen ball–box condition also failed to individuate the objects (i.e., if the narrow-screen infants failed to individuate the objects there would be no reason to believe that the wide-screen infants would succeed). This interpretation of the wide-screen results is inconsistent with the event-mapping results presented in the last section (Wilcox & Baillargeon, 1998a; Wilcox & Schwienle, in press; see also Leslie & Glanville, 2001). Recall that in the event-mapping experiments infants saw featurally distinct objects to each side of a wide screen; the screen was then lowered to reveal only one object. The screen used in the event-mapping experiments was exactly the same width as the screen used in the wide-screen conditions of the event-monitoring experiments, yet in the event-mapping experiments infants 5.5–11.5 months old gave evidence that they individuated the objects: The infants responded as if they had concluded that two objects were involved in the different-features event and were surprised to see only one object when the screen was lowered. In sum, not only is there is little evidence to support the claim that the narrow-screen results are simply an instantiation of the tunnel phenomenon, but there also is substantive evidence that argues against the viability of such a proposal.

The data presented in the first section of this chapter support the notion that infants younger than 11.5 months can use featural information to individuate objects in occlusion events but that they have difficulty demonstrating this ability when tested with an event-mapping task. When the information-processing demands typically associated with event-mapping tasks are reduced, infants as young as 5.5 months succeed. Furthermore, when tested with an event-monitoring task, infants as young as 4.5 months succeed. In the next section we explore infants' sensitivity to select object features.

INFANTS' DIFFERENTIAL SENSITIVITY TO FORM AND SURFACE FEATURES

In all of the individuation experiments described in the first section of this chapter, the objects seen to each side of the occluder varied on many dimensions, including shape, pattern, and color. The infants could have been using any one, or all, of these features to interpret the event. Object features can be grouped into two general categories: (a) features that specify three-dimensional form, such as shape, size, and rigidity, and (b) features that constitute surface properties, such as pattern, color, or texture (e.g., DeYoe & Van Essen, 1988). There is quite a bit of evidence that infants are sensitive to form features when reasoning about physical events (e.g., Aguiar & Baillargeon, 1998; Baillargeon, 1987, 1991; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987; Spelke, Brelinger, Macomber, & Jacobson, 1992); however, it is less clear whether infants also attend to surface features (e.g., Kotovsky & Baillargeon, 1998). These findings led us to suspect that young infants might be more sensitive to form than surface features when individuating objects within the context of occlusion events.

Shape, Size, Pattern, and Color Experiments

Wilcox (1999b) examined this possibility in a series of experiments by testing infants' sensitivity to two form features—shape and size—and two surface features—pattern and color—using the event-monitoring task described earlier. In each experiment, the objects seen to each side of the screen varied on only one dimension at a time. The results revealed that when the objects seen to each side of the occluder differed in shape (i.e., a green ball and a green box) or size (i.e., a large ball and a small ball), 4.5-month-olds used the difference to conclude that two distinct objects were involved in the event: They looked reliably longer in the narrow- than wide-screen condition. In contrast, when the objects seen to each side of the screen differed in their pattern (i.e., a dotted ball and a striped ball) or their color (i.e., a green ball and a red ball), infants were less likely to succeed; it was not until 7.5 months that infants used the pattern difference, and 11.5 months that they used the color difference, to reason about the number of objects present in the event.

It is noteworthy that these results are consistent with data recently obtained in investigations of infants' ability to individuate objects in static displays (see Needham et al., 1997, for a review). The basic finding in that literature is similar to that reviewed in the first section of this chapter; that is, when the surfaces visible to each side of an occluder differ in their featural makeup, 4.5-month-olds respond as if the surfaces belong to two separate and distinct objects. In contrast, when the surfaces are identical in their featural composition, 4.5-month-olds respond as if they perceive those surfaces as belonging to the same object. More important to the current discussion is that Needham (1999b) reported that 4-month-olds use shape but not pattern information to segregate stationary adjacent displays. In addition, Craton, Poirier, and Heagney (1998) found that 7- but not 4-month-olds use pattern to parse partly occluded displays. The results of these authors' studies are consistent with the developmental trends observed in Wilcox (1999b).

By 4.5 months, infants have relatively good pattern and color vision: They detect, respond to, categorize, and demonstrate memory for pattern and color features (Banks & Salapatek, 1981, 1983; Banks & Shannon, 1993; Bornstein, Kessen, & Weiskopf, 1976; Brown, 1990; Catherwood, Crassini, & Freiberg, 1989; Fantz, 1961; Greco, Hayne, & Rovee-Collier, 1990; Hayne, Rovee-Collier, & Perris, 1987; Salapatek, 1975; Teller & Bornstein, 1987). So why is it that the infants in Wilcox's (1999b) study failed to draw on pattern information until 7.5 months and on color information until 11.5 months? One possibility is that infants at these ages have not yet learned that pattern and color information can be used to keep track of the identity of objects as the objects move in and out of view; that is, even though the infants were capable of discriminating the difference between the two patterns (i.e., dots and stripes) and the two colors (i.e., green and red), they failed to consider this information as relevant to their interpretation of the event. An alternative explanation is that these infants have already identified pattern and color as one way to individuate objects but do not bring this knowledge to bear within the context of the narrow-screen task. According to this view, the infants recognized that pattern and color differences typically signal the presence of distinct objects, but they failed to apply this knowledge in that particular experimental context. Although the difference between these two explanations is subtle, they make different predictions. For example, according to the first view, infants would first need to learn that surface features could be used to individuate objects before demonstrating this knowledge. This presumably would take some time and would require the appropriate learning experience. In contrast, according to the second view, infants would not need to learn to use pattern and color but instead might simply need a more supportive context in which to reveal the knowledge that they already had.

Facilitating Infants' Use of Surface Features

One way to test between the two hypotheses just presented would be to present infants, prior to the individuation task, with events designed to make pattern and color features more salient, without actually "teaching" them that color and pattern could be used to individuate objects. Using this approach, infants' use of color features was first examined.

Color Findings. In one experiment, Wilcox and Chapa (2001) tested 9.5-month-olds (who fail to spontaneously draw on color features) using the narrow-screen procedure, with one exception: Prior to the test session, infants saw two pairs of pretest events, each pair consisting of a pound event and a pour event (see Fig. 6.9). In the first pair of pretest events the infants saw a green can with a handle pound a nail; they then saw a red can with a handle pour salt. The two cans were identical in appearance except for their color. In the second pair of pretest trials the infants saw the same events, except the green and red cans were replaced with green and red cups (see Fig. 6.10): The green cup pounded, and the red cup poured. The experimental session then proceeded as before. In the test trials, the infants saw an event in which a green ball and a red ball emerged successively to each side of a screen that was either too narrow (narrow-screen event) or sufficiently wide (wide-screen event) to occlude both balls at the same time (see Fig. 6.11). If infants have the knowledge that color can be used to individuate objects, but have difficulty calling forth this knowledge, then drawing their attention to color features in the pound–pour events should

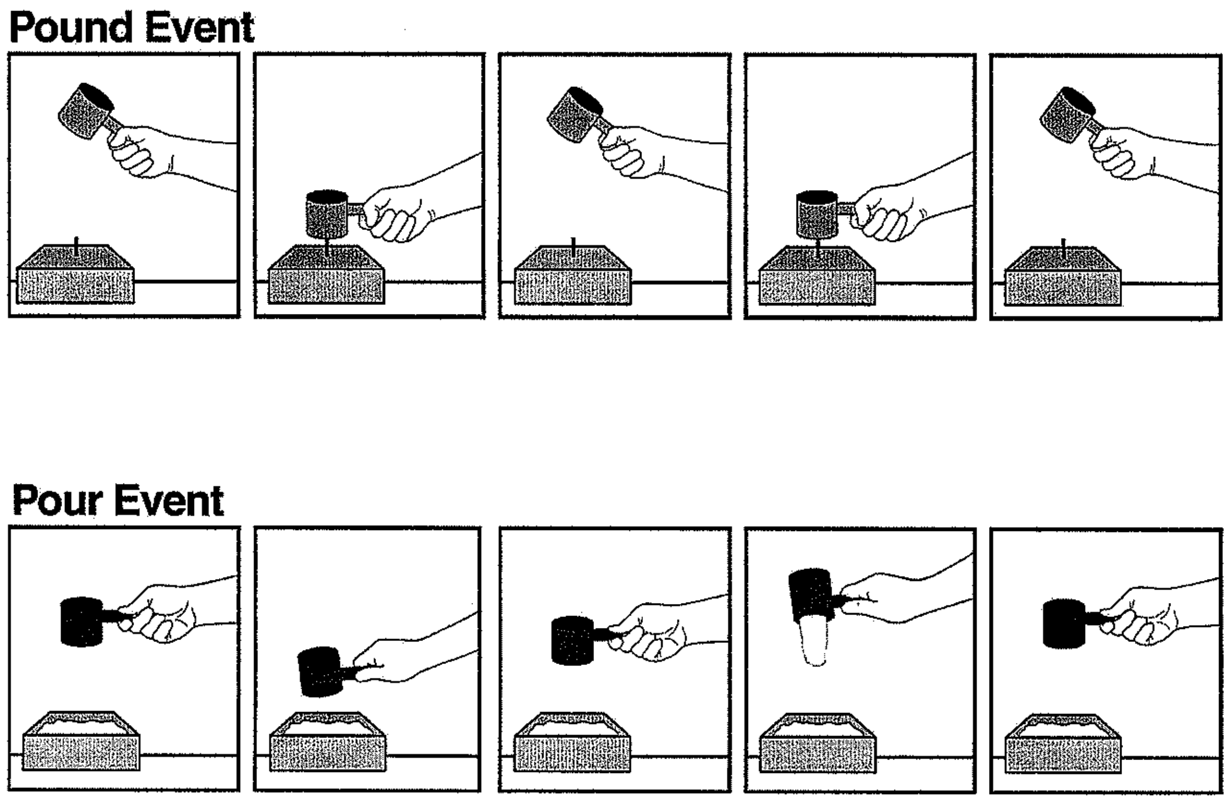

FIG. 6.9. The different-color pound–pour pretest events in Wilcox and Chapa (2001). The container that pounded was green, and the container that poured was red.

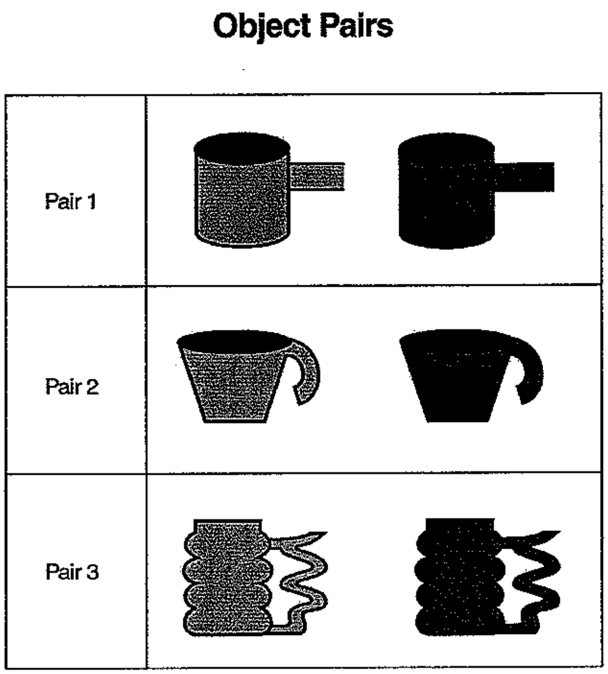

FIG. 6.10. The objects seen in the different-color pound–pour pretest events in Wilcox and Chapa (2001). The objects on the left were green, and the objects on the right were red. Infants ages 9.5 months saw Pairs 1 and 2, and infants aged 7.5 months saw Pairs 1–3.

improve performance on the individuation task. In contrast, if infants have not yet identified that color can be used to individuate objects, then showing infants the functional value of attending to color information should not lead to improved performance (i.e., infants were not taught, directly, that color could be used to individuate objects).

After viewing the pound–pour pretest events, the 9.5-month-olds looked reliably longer at the narrow- than at the wide-screen test event, as if the infants had (a) used the color difference between the green ball and the red ball to conclude that they constituted two distinct objects and (b) correctly judged that both balls could fit behind the wide screen but not the narrow screen. These results suggested that the infants recognized, when viewing the pound–pour events, that color was relevant to the situation before them. The infants' experience with color information in the pound–pour events—showing the infants the functional value of attending to color differences—heightened their sensitivity to color information, so that when presented with the different-color test event they successfully individuated the green ball and the red ball.

In designing the pound–pour experiment, Wilcox and Chapa (2001) made two assumptions about how infants go about forming representations of

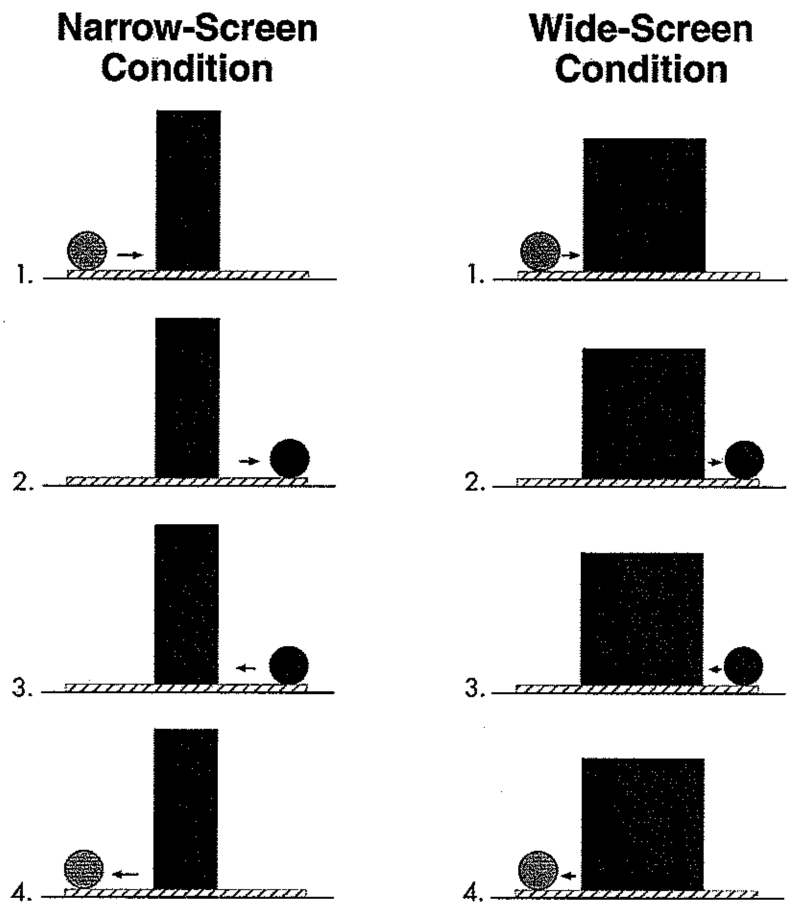

FIG. 6.11. The different-color narrow- and wide-screen test events in Wilcox and Chapa (2001). The ball seen to the left of the screen was green, and the ball seen to the right was red.

physical events. The first was that infants are sensitive to object function when interpreting physical events (e.g., Greco et al., 1990; Kolstad & Baillargeon, 1993; Nelson, 1974; Pieraut-LeBonniec, 1985; see Pick, 1997, for evidence with young children). More specifically, they assumed that infants would find events involving object function compelling—so compelling, in fact, that information garnered during those events would influence their interpretation of subsequent events. However, it is possible that they overestimated the importance of object function to the early representational system. To examine this possibility, they tested another group of 9.5-month-olds using the same procedure, with the following modifications. In the pound event, the green containers moved up and down, to the right of the nail without ever coming into contact with the nail; in the pour event, the red containers made scooping and pouring motions, to the right of the container holding the salt, without acquiring and releasing salt (see Fig. 6.12). In each of these events the objects' motions were accompanied by sounds similar to those made by the objects when they were actually pounding and pouring. Hence, the main difference between these pretest events, and those in the pound–pour experiments, was that the actions in which the objects engaged were not functionally relevant. As before, the pretest events were followed by the narrow- or wide-screen test event.

The 9.5-month-olds in the motion experiment looked about equally at the narrow- and wide-screen test event, suggesting that they did not view the green ball and red ball as two distinct objects. Simply seeing the green and red pretest objects perform distinct actions was not sufficient to induce the infants to use color features to individuate the objects in the test event. It was seeing the pretest objects perform different functions that drew infants' attention to color information. These results are intriguing, because they suggest that when reasoning about physical events infants distinguish between different kinds of actions on objects and weight those actions differently. Actions that are functionally relevant are particularly salient to infants, whereas actions that are not functionally relevant fail to have the same impact.

The second assumption Wilcox and Chapa (2001) made in designing the pound–pour experiment was that infants would need to see at least two different pairs of pretest objects to benefit from viewing the pound–pour events (Baillargeon, 1998). If infants saw only one object pair, they would treat it as a unique situation (i.e., the green can pounds, and the red can pours) and hence fail to extract the more general rule that the green objects functioned differently than the red objects. In a test of this assumption, an additional group of 9.5-month-olds saw the same pretest and test events as the infants in the pound–pour experiment, with one exception: The first pair of objects (i.e., the green can and red can) were shown on both pairs of pretest events. The infants looked about equally at the narrow- and wide-screen test event, suggesting that seeing only one object pair in the pretest events was not sufficient to facilitate their use of color features in the test event. The negative results obtained in the one-exemplar experiment, together with the positive results in the original pound–pour experiment, suggest that infants, when viewing complex physical events, attempt to group the objects or events before them into meaningful categories. Furthermore, infants' categorical representation of one physical event can alter their interpretation of another, separate event. Put more strongly, infants' propensity to form categorical representations of physical events is a powerful tool. It allows infants to organize the physical world as it unfolds before them, and it provides a structure with which to interpret future events.

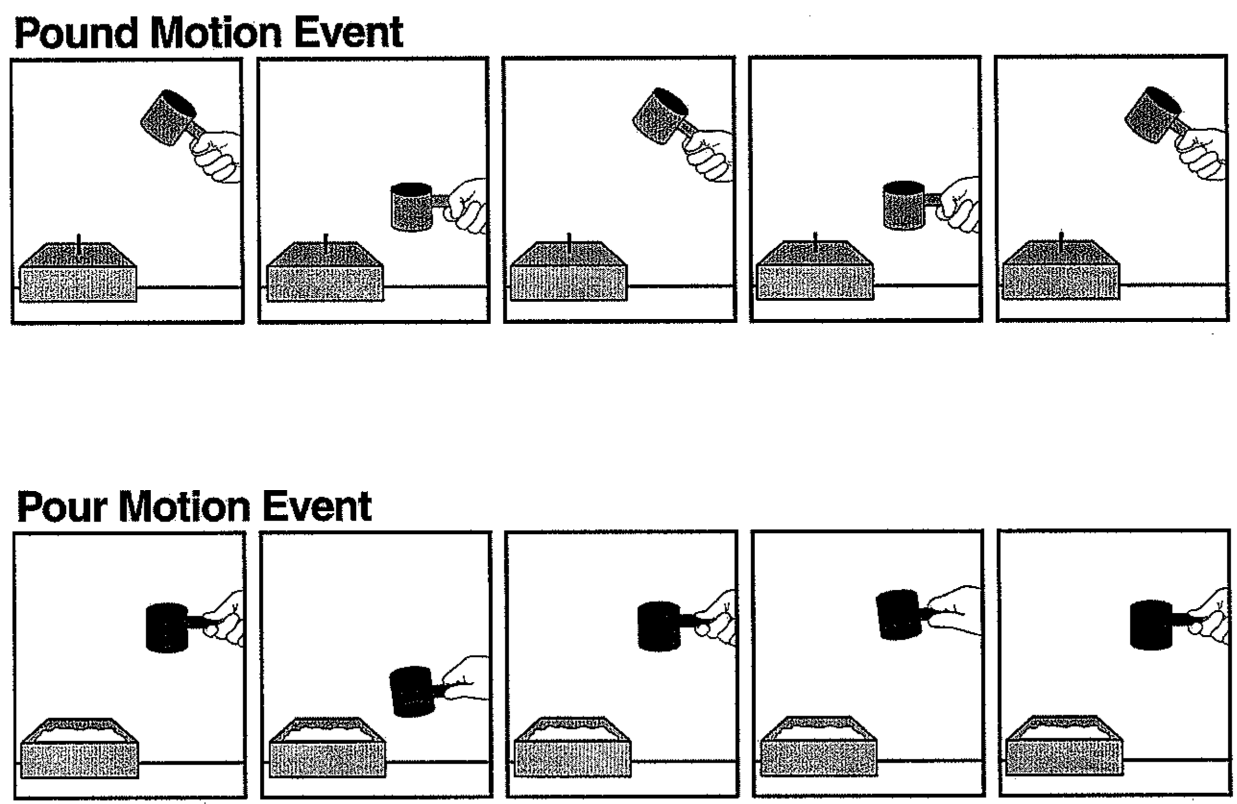

FIG. 6.12. The different-color pound–pour motion pretest events in Wilcox and Chapa (2001). The container in the pound motion event was green, and the container in the pour motion event was red.

Given the importance of the ability to form and use categorical event representations, one might wonder about the ontogeny of this ability. Hence, additional experiments were conducted with 7.5-month-olds (Wilcox & Chapa, 2001). These younger infants were tested using the same procedure: The infants saw the pound–pour pretest events followed by the different-color test events. The initial findings were negative; however, follow-up experiments revealed that 7.5-month-olds can benefit from viewing the pound–pour events, but only when they are allowed to see three pairs of pretest events, with three different objects pairs (se Fig. 6.10). It is important to point out that it is not increased exposure to the events, per se, that facilitates infants' performance, but rather an increase in the number of object pairs with which infants are presented. If infants see three pairs of pretest events, but these events involve only two object pairs (i.e., the second pair is seen twice), then performance is not improved compared with that of infants who see two pairs of pretest events with two object pairs. The fact that the younger infants need to see more exemplar pairs in order to benefit from the pound–pour procedure suggests that they are not as quick to form a categorical representation of the pound–pour events.

This general pattern of results, that younger infants need to see more exemplar pairs, is consistent with results recently obtained by Baillargeon and her colleagues (Baillargeon, 1998) in recent investigations of infants' understanding of support events. In their experiments, infants were presented with training trials to help teach them variables important for interpreting support events. She found that 11.5-month-olds learn a new support variable (i.e., proportional distribution) when given two, but not one, exemplar pairs, and that 11-month-olds learn the same variable when given three, but not two, exemplar pairs.

Pattern Findings. The positive color results obtained with the 9.5- and 7.5-month-olds led Wilcox and Chapa (2001) to ask whether infants might be flexible in their use of other surface features as well. For example, perhaps infants younger than 7.5 months (the age at which infants first succeed at using pattern information) could be led to attend to pattern differences using the pound–pour procedure. To answer this question they tested 5.5- and 4.5-month-olds using the pound–pour procedure, with one exception: The green containers and red containers were replaced with dotted containers that pounded and striped containers that poured (see Fig. 6.13). The infants saw three pairs of pretest events involving three different object pairs (see Fig. 6.14). In the test events, a dotted ball moved to the left of the screen, and a striped ball moved to the right. The screen was either too narrow, or sufficiently wide, to hide the dotted ball and striped ball simultaneously (see Fig. 6.15). The 5.5-month-olds looked reliably longer at the narrow- than at the wide-screen test event, suggesting that they had used

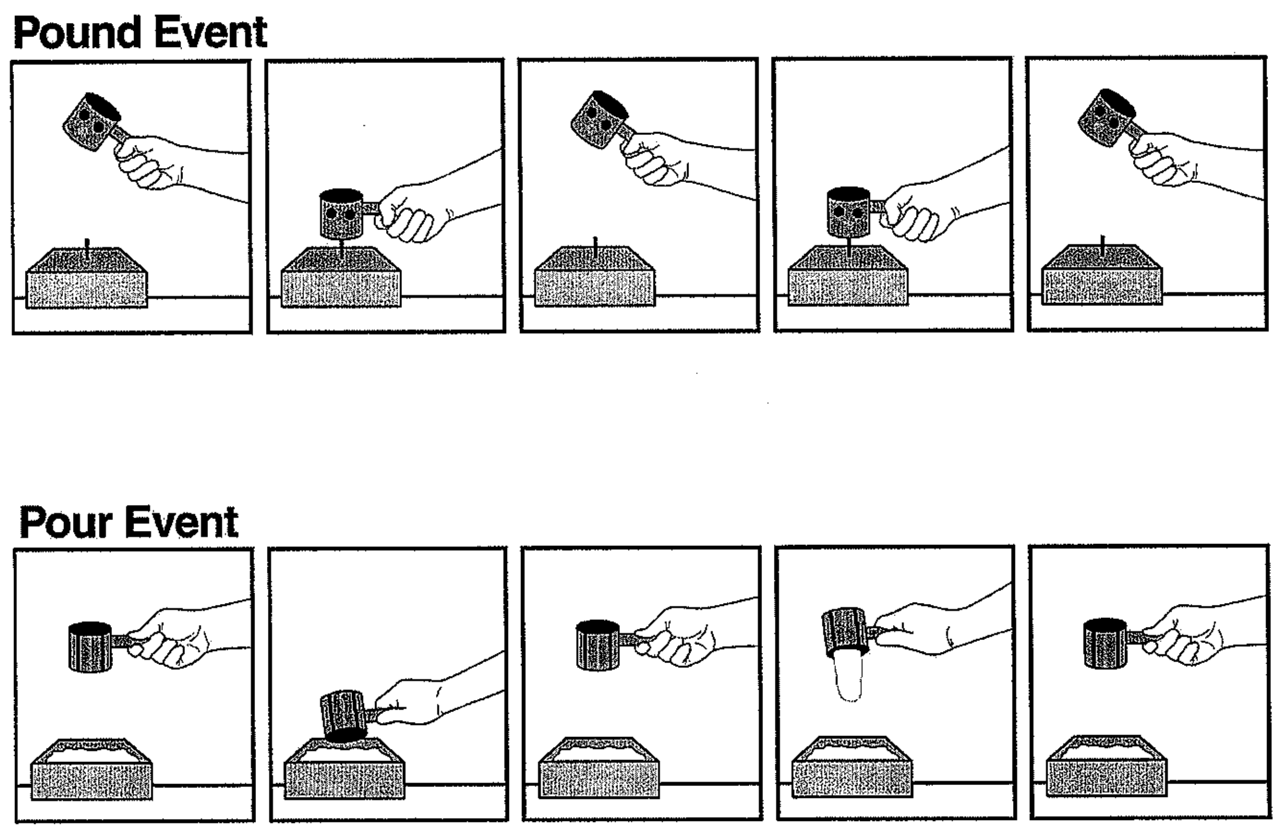

FIG. 6.13. The different-pattern pound–pour pretest events in Wilcox and Chapa (2001).

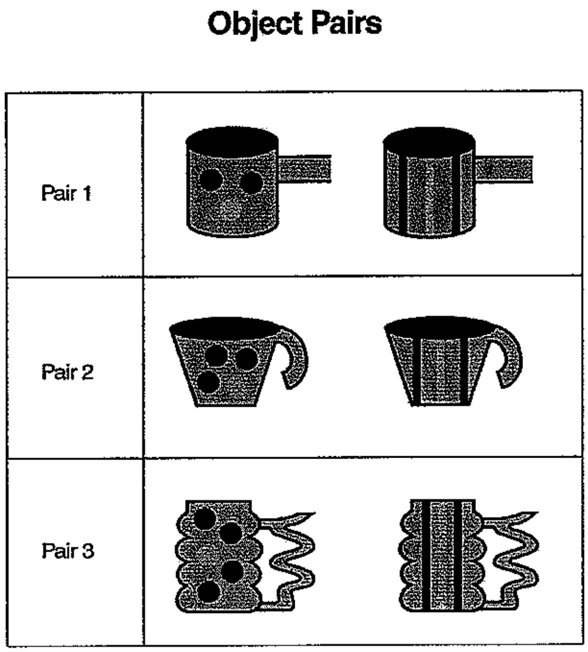

FIG. 6.14. The objects seen in the different-pattern pound– pour pretest events in Wilcox and Chapa (2001).

the pattern difference to conclude that two objects were involved in the test event and recognized that both objects could not be behind the narrow screen at the same time. In contrast, the 4.5-month-olds looked about equally at the two test events, suggesting that they did not realize that two distinct objects were present in the event.

Although one might conclude from the negative results obtained with the 4.5-month-olds that these younger infants had not yet identified pattern information as a means of individuating objects, an alternative interpretation of these results might be considered. It is possible that the 4.5-month-olds failed not because they were unable to individuate objects on the basis of pattern features but because of information-processing constraints. Perhaps the younger infants had difficulty following the pound–pour events and keeping track of which pretest object did what during each trial. If the infants were unable to keep track of each object and the function that it performed, then they would not have been able to form a categorical representation of the pretest events. To test this hypothesis, additional infants were tested in a condition in which the containers were seen together in the pretest events (see Fig. 6.16): In the pound event the striped cup sat to the left of the display, and in the pour event the dotted cup sat to the left of the display. The results were quite striking. When the infants saw the dotted and

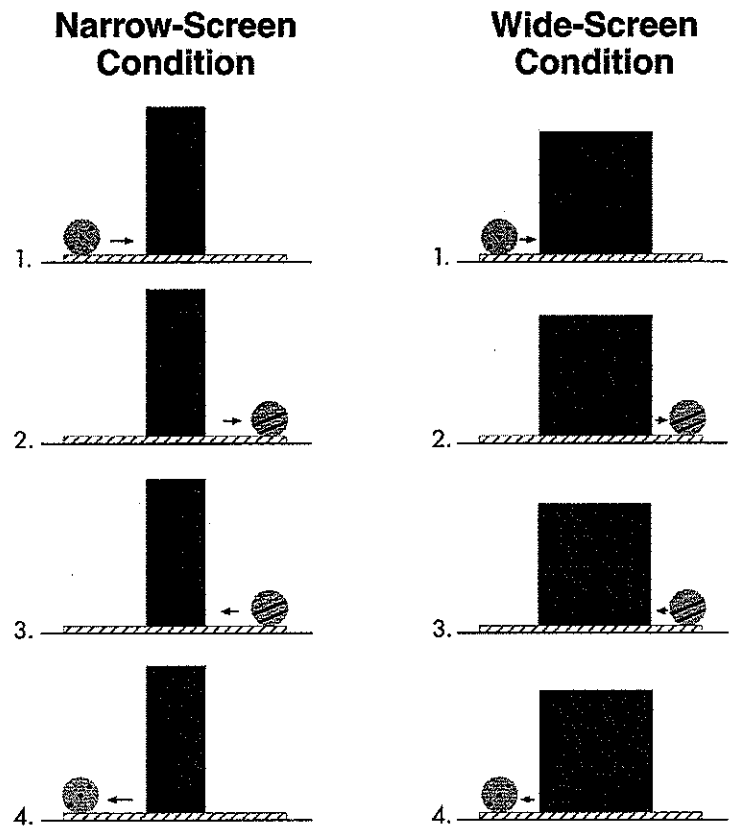

FIG. 6.15. The different-pattern narrow- and wide-screen test events in Wilcox and Chapa (2001).

striped containers simultaneously, so that they did not need to recall what the other container looked like—it was right before them—the 4.5-month-olds performed like the 5.5-month-olds: In the test event they used the pattern difference between the dotted and the striped ball to conclude that they constituted two distinct objects.

Why did seeing the objects together in the pretest trials make such a difference? There are at least two possibilities. One is that seeing the objects together gave the infants the opportunity to directly compare and contrast the two containers and highlighted the fact that containers with different featural properties performed different functions. This experience led infants to attend more closely to the categorical distinctions between the two containers (Namy, Smith, & Gershkoff-Stowe, 1997; Needham, Dueker, & Lockhead, 2001; Oakes, 2001; Quinn, 1987). According to this hypothesis,

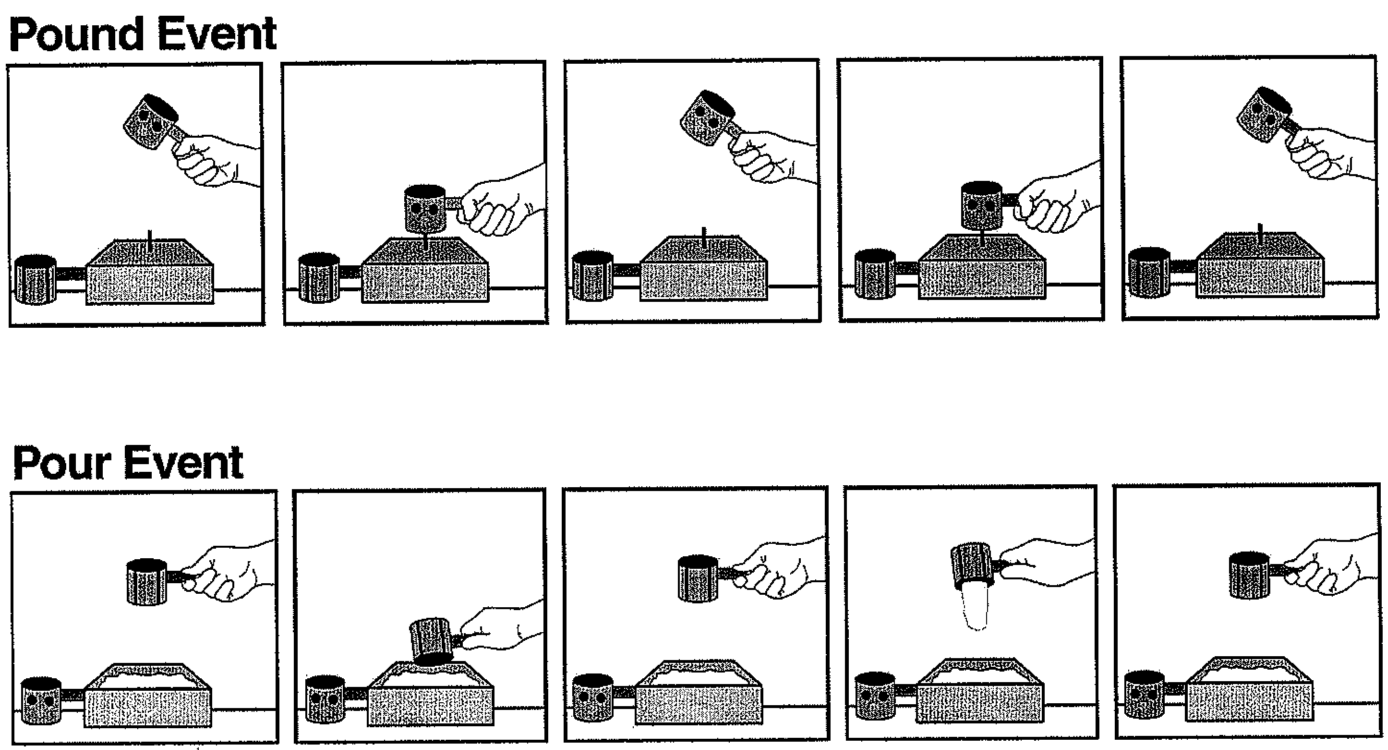

FIG. 6.16. The different-pattern pound–pour pretest events in Wilcox and Chapa (2001), in which the objects were seen simultaneously.

the infants had difficulty recognizing and extracting information that was important for category formation (i.e., dotted containers pound and striped containers pour), and seeing the containers together facilitated this process. Another possibility is that the infants had difficulty retrieving information about the featural properties of the container that was not in view. Because only one object was seen at a time, the infants had to rely on their memory of the previously seen container to make the comparison between the two containers. As the events transpired before them, the infants may have been unable to keep track of each container and what it looked like. According to this hypothesis, a memorial limitation best explains the 4.5-month-olds' failure to form a categorical representation of the pretest events.

Although the data, as they currently stand, do not distinguish between these two possibilities, we tend to favor the former, for two reasons. First, there is evidence that 4- and 6-month-olds form more sophisticated categories when they are allowed to directly compare exemplars than when they are presented with exemplars one at a time and that this effect cannot be easily explained by age-related changes in memory (Oakes, 2001). Second, there is evidence that infants' memory for featural information is quite robust, often lasting over several weeks (Rovee-Collier, 1995, 1997). Although the infants in Wilcox and Chapa's (2001) experiments had to do more than simply remember one set of features—they had to compare and contrast two sets of features—the memory demands associated with the task seem to fall within the bounds of infants' memory capabilities.

Differential Sensitivity to Features: Further Discussion

The findings obtained in the differential-sensitivity experiments can be summarized in the following way. Form features are very salient to young infants. By 4.5 months, infants identify form features as a way to individuate objects, and they use these features reliably. In contrast, surface features are less salient. Even after infants have identified surface features as a basis for object individuation, between 7.5 and 11.5 months, they do not spontaneously use this knowledge in occlusion situations. It is only with a more supportive context that infants succeed. These results raise two important questions: (a) Why do infants demonstrate sensitivity to form features before surface features? and (b) How did the pound–pour pretest events increase infants' sensitivity to surface features? In the following sections we attempt to answer these two questions, and then we conclude with some additional comments.

Why Do Infants Demonstrate Sensitivity to Form Features Before Surface Features? The developmental sequence observed in the features experiments may reflect, at least to some extent, the nature of the developing visual system. Because visual acuity and color vision are initially quite poor, infants may simply have difficulty getting good pattern and color information. In addition, infants may perceive object form as more stable across viewing conditions than surface characteristics. There is evidence that, from birth, infants experience size constancy (Granrud, 1987; Slater, Mattock, & Brown, 1990) and shape constancy, at least in some situations (Slater & Morison, 1985; see also Kellman, 1984; Kellman & Short, 1987; Yonas, Arterberry, & Granrud, 1987). In contrast, infants do not demonstrate color constancy until about 4–5 months of age, and then only under limited conditions (Dannemiller, 1989; Dannemiller & Hanko, 1987). Finally, infants may not have equal exposure to form and surface features. Form features are amodal—they can be experienced haptically, orally, visually. Consequently, infants may have a greater number of, and more varied, experiences with form features.

However, sensory experiences cannot fully account for the results discussed earlier. Infants detect, respond to, and demonstrate memory for pattern and color information long before they spontaneously use this information to individuate objects in occlusion events (Wilcox, 1999). What other factors might contribute to infants' differential responding to form and surface features? We suspect that these results also reflect infants' bias to attend to form features when reasoning about occlusion events. The shape and size of an object, relative to those of an occluder, determine whether the object can be fully or only partially occluded. In contrast, the pattern and color of the object often have little predictive value. Whether an object is red, green, dotted, or striped has no bearing on whether it will become fully or only party occluded. With experience, however, infants may come to realize that pattern and color information can sometimes be useful when reasoning about objects in occlusion events. This experience would lead infants to identify pattern and color as important variables and then use this information to make judgments about the number of objects present in an occlusion event.

It is also possible that the present results reflect a more general bias to attend to form over surface features when reasoning about physical events. In most physical situations, form features are more important than surface features. For example, in containment events, the size and shape of an object relative to those of a container determine whether the object can fit into the container; in support events, the dimensions and placement of an object relative to a supporting surface determine whether the object will remain supported or fall to the ground; and in collision events, the size and weight of a moving object determines how far a stationary object will be displaced on contact (Aguiar & Baillargeon, 1998; Baillargeon, 1995, 1998; Baillargeon et al., 1995; Kotovsky & Baillargeon, 1998). Rarely are surface features crucial to making predictions about the outcome of such events. As a result, infants assign them little importance. This hypothesis predicts that, although the age at which infants first recognize pattern and color information as relevant to a physical situation may vary across event categories, within each event category infants would first identify form, then surface, features as important variables. Although this hypothesis has yet to be tested directly, there is preliminary evidence that this holds true for collision (Kotovsky & Baillargeon, 1998), as well as occlusion, events.

How Did Viewing the Pound–Pour Pretest Events Increase Infants' Sensitivity to Surface Features? The results obtained in the pound–pour experiments indicate that there is a certain amount of flexibility in the object representation system. Select experiences with objects, or categories of objects, can alter infants' sensitivity to some sources of information. It is important to point out that the positive results obtained in the pound–pour experiments are not specific to just those functions. We have recently collected data in our laboratory indicating that other feature–function pairings (i.e., green spoon-shaped objects stir and red spoon-shaped objects lift) can also facilitate individuation performance. How can viewing one event change infants' sensitivity to surface features in another, separate event? In the pound–pour experiments the only way that infants could distinguish between the pretest objects, and the function in which the objects would engage, was to use surface features. We suspect that the experience of using surface features as a marker of object function primed the physical reasoning system to attend to surface features. This resulted in increased sensitivity to surface features in subsequent events. This analysis raises many interesting questions. For example, one might question the extent to which infants generalize the experience of using surface features to make predictions about object function. On the one hand, their representation of this experience might be relatively general, such as "objects with different features perform different functions." On the other hand, their representation of this experience might be quite specific, such as "green objects pound, and red objects pour." If the former is correct, then viewing the red and green containers in the pound–pour events should facilitate infants' use of any color difference (e.g., yellow and blue balls) in the test event. An even stronger prediction would be that viewing different-colored containers in the pound–pour events would facilitate infants' use of other surface features, such as pattern, in the test event. We are currently testing these predictions.

One might also wonder how long surface features stay primed. Is the effect fleeting, or will it last over an extended period of time? What other kinds of experiences might lead infants to attend to surface features? In response to this last question, we are exploring how different types of pre-exposure might facilitate infants' use of color features (e.g., Boller, 1997; Grandrud, Haake, & Yonas, 1985; Needham, 2001; Needham & Baillargeon, 1998). For example, in one series of experiments, Chapa and Wilcox (1999) found that 10.5-month-olds, like 9.5-month-olds, failed to spontaneously use color differences to individuate objects in the narrow- screen task. However, if the 10.5-month-olds were allowed to manipulate the green ball and the red ball, one at a time, prior to the test event, they then drew on the color difference to correctly interpret the green ball–red ball test event. Furthermore, the type of experience that the infants had with the objects, and the context in which the experience occurred, was important. The infants demonstrated increased sensitivity to color features in the test event only when (a) they were allowed to physically touch the balls rather than just look at them and (b) this experience took place in a context that was distinct from that in which they saw the test event. We suspect that manual exploration—physically touching the balls' surfaces—was necessary to draw infants' attention to the color of the balls and that the infants recognized the value of attending to these features only when they were required to keep track of the objects across different contexts.

Additional Comments. Although we have focused here on the development of infants' use of spatiotemporal and featural information to individuate objects, we do not mean to suggest that these are the only two sources of information available to infants. There are other types of information that infants might find useful when tracking the identity of objects through space and time (Meltzoff & Moore, 1998; Needham et al., 1997; Wilcox & Baillargeon, 1998a). For example, some researchers have argued that infants can also draw on physical information (i.e., knowledge about the lawful ways that objects move and interact) and experiential knowledge (i.e., information acquired about specific objects or categories of objects) to individuate objects in occlusion events (Needham et al., 1997; Wilcox & Baillargeon, 1998a). Although we do not present all of the evidence here, a recent object segregation experiment conducted by Needham (1999a; also cited in Needham & Baillargeon, 2000), in which infants' use of featural information and experiential knowledge were cleverly pitted against each other, is especially striking. In this experiment, 5.5- and 7.5-month-olds were presented with a partly occluded static display that consisted of a large keyring whose center was hidden by a narrow screen, so that the ring portion protruded to the left of the screen and the key portion to the right. The infants watched a test event in which a hand grasped the ring portion of the keyring and moved it in depth, away from the infant (the center portion of the display remained occluded by the screen). For some infants, the key portion of the display moved with the ring portion, as if the pieces were connected behind the screen; for the other infants, the ring remained stationary, so that the pieces broke apart as the ring moved away in depth. The 5.5-month-olds were surprised to see the units move together, suggesting that they had interpreted the display in accordance with its featural properties. In contrast, the 7.5-month-olds were surprised to see the ring and key break apart, suggesting that they had brought to bear their knowledge of keyrings, a category of objects with which they have had a fair amount of experience, to interpret the display.

OBJECT INDIVIDUATION AND OBJECT IDENTIFICATION

The individuation results presented in the previous two sections shed light on how infants go about establishing representations of numerically distinct objects. There seems to be little doubt that even young infants use featural information to individuate objects in occlusion events. What we have not yet addressed is how infants represent, in short-term memory, the physical entities that they individuate. This problem is best understood within the context of the distinction, recently made by Leslie and his colleagues, between object individuation and object identification (Kaldy & Leslie, 2001; Leslie et al., 1998; Scholl & Leslie, 1999; Tremoulet et al., 2001). *Individuation by feature* refers to the process by which featural information is used to draw conclusions about how many objects are present in an event. When featural differences are detected, they signal the presence of distinct objects. In contrast, *identification by feature* is the process by which featural information is used to identify an object as having been previously seen. This involves not only detecting featural differences but also specifying the nature of those differences. More important, it is possible for infants to individuate objects on the basis of featural differences yet fail to identify those same objects by their featural properties.

To illustrate, consider recent experiments reported by Leslie and his colleagues (Leslie et al., 1998; Tremoulet et al., 2001) in which an event-mapping task was used. In an individuation experiment (Tremoulet et al., 2001), 12-month-olds were assigned to one of two conditions: shape or color. The infants in the shape condition saw an event in which two different-shaped objects (i.e., a circle and a triangle) emerged sequentially to one side of a screen. The screen was then removed to reveal either one object (i.e., a circle) or two objects (i.e., a circle and a triangle) on the platform. The same procedure was used for the infants in the color condition, except that the objects differed in color rather than in shape: The infants saw two different-colored objects (i.e., a green circle and a red circle) emerge sequentially to one side of the screen followed by a display containing either one object (i.e., a green circle) or two objects (i.e., a green circle and a red circle). The infants in both the shape and the color condition gave evidence that they individuated the objects: They responded as if they expected to see two objects when the screen was removed and were surprised to see just one. Now we look at the results obtained in an identification experiment (Tremoulet et al., in press). Infants 12 months of age were again assigned to one of two conditions: shape or color. As before, the infants in the shape condition saw a circle and a triangle emerge sequentially to one side of a screen. However, this time when the screen was removed infants saw either a circle and a triangle (consistent display) or two circles (inconsistent display) or two triangles (inconsistent display). The infants in the color condition saw a similar event except that the objects differed in color: In the initial phase, the infants saw a green circle and a red circle emerge sequentially to one side of the screen, and in the final phase infants saw either a green circle and a red circle (consistent display) or two green circles (inconsistent display) or two red circles (inconsistent display). The infants in the shape condition looked reliably longer at the inconsistent displays than at the consistent display, suggesting that they expected to see two different-shaped objects, a circle and a triangle, when the screen was lowered and were surprised when this expectation was violated. In contrast, the infants in the color condition looked about equally at the consistent and inconsistent displays, as if they had no expectation for the color of the objects that should be present on the platform. These results are particularly intriguing, because they echo the shape and color results Wilcox (1999) obtained using an event-monitoring task. It is clear that infants use shape and color information in different ways when reasoning about objects in occlusion events.

Object Identification and the Binding Problem

The experiments conducted by Leslie and his colleagues raise questions about the extent to which infants incorporate features in their object representations. It is clear that infants use features to individuate objects, but it appears they may not retain in their representations of those objects the different features that were used to individuate them in the first place. Consider the implications of these ideas for the simplified event-mapping task used by Wilcox and Schweinle (2002) that was discussed earlier. In the egg–column condition of that experiment (see Fig. 6.5), an egg moved behind the left side of a screen, and a column emerged at the right; the screen was then lowered to reveal a single column on the platform. The distinction between object individuation and object identification implies that there were two different ways that the 7.5- and 5.5-month-olds could have represented the egg–column event, either of which would have led them to respond with increased looking to the one-column display. One possibility is that the infants represented the egg–column event as involving two objects, one that moved to the left of the screen and another that moved to the right. When the screen was lowered, the infants were surprised to see a single object on the platform. According to this view, the infants represented the number of objects that they had seen in the occlusion event and recognized when the final display was inconsistent with this number, without actually calling forth the featural composition of each of the objects. Alternatively, the infants may have represented the egg–column event as involving two specific objects, an egg to the left of the screen and a column to the right. When the screen was lowered, the infants were surprised to see only the column on the platform. According to this view, the infants successfully represented both the number and the featural properties of the objects involved and were surprised when the final display failed to contain the egg. Because either one of these representations—"two objects" and "an egg and a column"—would have led the infants to judge the final one-column display as unexpected, the results, as they stand, are not sufficient to distinguish between these two possibilities.

At this point one might wonder how infants could draw on features to set up representations of objects yet fail to include those features in their object representations. The issue of how and when features get linked to objects has been referred to as the *binding problem* (e.g., Treisman, 1995). According to one theory of object-based perception, the *object file theory* (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992; Treisman, 1988, 1995), people are equipped with temporary structures—referred to as *object files*—where information about currently visible objects is collected.[3] An object file (i.e., the percept of a new object) is created when object properties (e.g., location, color, shape) are believed to have changed. To use a familiar example, seeing the green ball to one side of the screen would initiate the opening of one object file, whereas seeing the box to the other side of the screen would result in the opening of another. Object files contain information about both the spatiotemporal and featural properties of objects, although they are addressed primarily by spatiotemporal coordinates. Soon after objects disappear from view, or can no longer be directly perceived, object files are stored as memory tokens. However, because information about the spatiotemporal and featural properties of objects is processed and stored separately, a view supported by research in the neurosciences (Desimone & Ungerleider, 1989; Livingstone & Hubel, 1988; Ungerleider & Mishkin, 1982), a unified representation requires that they be joined together in some way. If this information is not joined together, one may retrieve information about where an object is located, or what features are present, without being able to specify which features are located where. Building on these ideas, some researchers have suggested that the

[3]There are other theories of object-based perception that could also be used as a framework for understanding the binding problem (e.g., Leslie et al., 1998; Pylyshyn, 1989, 1994). For a concise review of several different theories and how at least one might be used to understand object representation in infancy, see Leslie et al. (1998) or Scholl and Leslie (1999).

mechanism responsible for binding together spatiotemporal and featural information is not well developed in young infants (Leslie et al., 1998).

Object Identification and Feature Binding in 7.5- and 5.5-Month-Olds

To examine object identification and feature binding in young infants, Wilcox and Schweinle (in press) presented 7.5- and 5.5-month-olds with the egg–column test event described earlier, with one exception: When the screen was lowered, the final display contained either two columns (experimental condition) or an egg and a column (control condition; see Fig. 6.17). If infants represented the egg–column event as involving two objects, but failed to include in their representation the featural composition of those objects, then they should not be concerned with the featural properties of the objects in the final display, as long as the display contained two objects. In contrast, if infants represented the egg–column event as involving two specific objects, an egg and a column, then they should expect to see those two objects, and only those two objects, in the

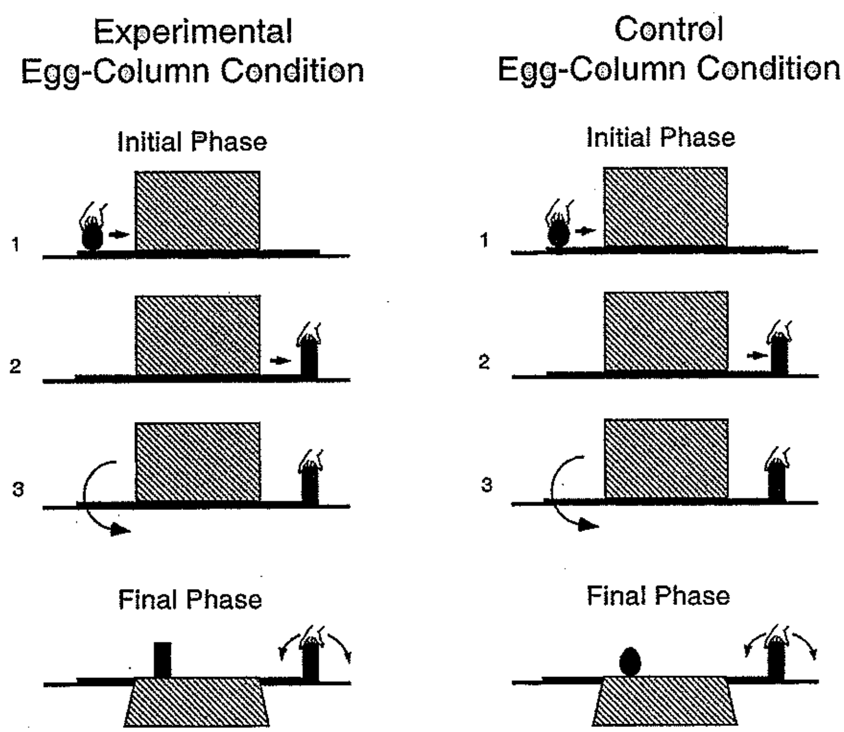

FIG. 6.17. Experimental and control egg–column test events in Wilcox and Schweinle (2002).

final display. A different pattern of results was obtained for the two age groups, so we discuss their data separately.

The 7.5-month-olds looked reliably longer at the two-column display. On the basis of the rationale presented earlier, we took these results to mean that the infants (a) had coded the egg–column event as involving two featurally distinct objects, an egg and a column; (b) expected to see an egg and a column when the screen was lowered; and (c) were surprised when this expectation was violated. However, there is reason to be cautious in accepting this interpretation. It is possible that the infants found the final display containing the two columns unexpected for a slightly different reason. The infants could have represented the event as involving two featurally distinct objects, without coding, more specifically, what those features were. If this were the case, then infants would find the final display containing two columns unexpected because it contained two featurally identical objects. To evaluate this possibility, Wilcox and Schweinle (2002) tested another group of infants in a modified experimental condition. In this condition, infants saw a test event in which two featurally distinct objects were seen in the initial and the final phases of the test event, but the objects seen in the two phases did not match. In the initial phase, a triangle moved behind the left side of the screen and a column emerged at the right side; in the final phase, an egg and a column were seen on the platform. Prior to the test event, infants were familiarized to all three objects—the triangle, the egg, and the column—so that increased looking times could not be attributed to a preference for a display containing a novel object. If infants represented the triangle–column event as involving two specific objects, a triangle and a column, then the infants in the modified experimental condition should find the final display, which contained an egg and a column, surprising or unexpected. In contrast, if infants represented the triangle–column event as simply involving two featurally distinct objects, then they should find the final display consistent with this representation. The looking times of the infants in the modified experimental condition during the final phase of the test event were compared to those of the infants in the experimental and control conditions. The infants in the modified experimental condition looked reliably longer than infants in the control condition, and their looking times did not differ reliably from infants in the experimental condition. Together, these results suggest that 7.5-month-olds represent different-features events as involving two distinct objects, specified by their featural composition, rather than simply as two different objects.[4]

[4]Of course, these data do not tell us which features the infants were using to identify the objects. The objects differed in their shape and color and in whether they had a pattern (i.e., the egg was plain yellow, and the column was multicolored with yellow, blue, and red stripes). The results obtained by Tremoulet et al. (2001) suggest that the infants were probably using shape, but not color, to identify the objects. Whether infants were also using pattern versus no pattern is open to speculation.

In contrast to the 7.5-month-olds, the 5.5-month-olds in the experimental and control conditions looked about equally during the final phase of the test event, as though they failed to detect the discrepancy between the egg–column event and the two-column display. Recall that in experiments described earlier, 5.5-month-olds responded as if they had detected a discrepancy between the egg–column event and the presence of only one object in the final display (Wilcox & Schweinle, 2002). Together, these data suggest that when mapping different-features events 5.5-month-olds give evidence that they individuate objects by feature (i.e., they expect to see two objects when the screen is lowered) but not that they identify objects by feature (i.e., they hold no expectation for the featural properties of those objects).

Why did the 7.5-month-olds respond as if they had included featural information into their object representations, whereas the 5.5-month-olds did not? Why did the younger infants individuate the objects by feature but then fail to identify them by feature? We now draw again from object file theory. According to Treisman (1995), the binding problem can take many different forms. For example, in location binding, objects are bound to locations. By extension, moving objects are bound to their trajectories. Likewise, in property binding features are bound to the objects that they characterize. Wilcox (1999a) and Wilcox and Schweinle (2002) have suggested that, when building representations of physical events, infants' first and primary task is to extract the simple, or spatial, structure of the event. In the egg–column event this would mean identifying the trajectory that each object followed, including where each object stopped, started, and reversed direction when behind the screen. We suspect that infants may have difficulty reasoning about occluded trajectories, especially when path of motion is altered during occlusion. If so, it is quite possible that the younger infants had difficulty extracting the simple structure of the egg–column event. Without the simple structure, infants would be unable to integrate featural information into their representation of the event.

Perhaps, then, the 5.5-month-olds' failure to identify the objects by feature reflects an underlying difficulty in identifying the simple structure of the egg–column event: Before features can be bound to objects, infants first must identify the spatiotemporal coordinates of those objects. This hypothesis makes the following prediction: If the simple structure of the event were made more clear, then 5.5-month-olds would succeed at binding features to objects. How might one make the simple structure clearer? One way would be to present infants with unambiguous information as to the number of objects involved in the event and the trajectories that they follow. Recent experiments conducted in our laboratory have taken this approach (Wilcox & Schweinle, 2002; see also Kaldy & Leslie, 2001). Infants 5.5 months of age saw the egg–column event, with one exception: The wide screen was replaced by two narrow screens separated by a small gap, so that the egg and column moved behind spatially separate screens. As before, the egg–column event was followed by a display containing either two columns (experimental condition) or an egg and a column (control condition). When the egg–column event was seen with two separate screens, so that the simple structure was made explicit, the infants now looked reliably longer at the two-column final display than at the egg–column final display, as though they recognized that the egg–column event was inconsistent with the two-column display.

As with the 7.5-month-olds, a follow-up experiment was conducted to examine why the 5.5-month-olds found the two-column display unexpected. Did they expect to see two specific objects or just two featurally distinct objects? The infants were tested in a modified experimental condition identical to that used with the 7.5-month-olds, with one exception: The wide test screen was replaced by two narrow screens. (Recall that in the modified experimental condition the infants saw a triangle and column in the initial phase of the test event and an egg and a column in the final phase.) The infants in the modified experimental condition responded like those in the control condition, and their looking times differed reliably from those of the infants in the experimental condition. The infants thus expected to see two featurally distinct objects on the platform but failed to identify, more specifically, what features each of those objects possessed.

The most intriguing aspect of these results is that they suggest that, under some conditions, infants are able to mark, or tag, objects in a way that distinguishes them from other objects, without assigning to each object the specific information that makes them distinct. These results raise many questions about the processes involved. For example, is tagging objects as featurally distinct and binding features to objects part of the same process, or are they two separate functions? It is not clear whether object file theory, or other theories of object perception, can account for these results with the notion of feature binding. How might tagging work? For example, was the triangle represented, abstractly, as "X" and the column as "not X," and then each object aligned and compared to the objects in the final display? Or, alternatively, was the event as a whole represented as "two featurally distinct objects" and this unit compared to the two-object unit in the final display? What leads to developmental changes in the ability to link features to objects in short-term memory? Is the mechanism involved specific to objects and their features, or is the same mechanism responsible for binding together many different elements of an event (e.g., Cohen & Eichenbaum, 1993; Nadel & Moscovitch, 1997; Squire, Cohen, & Nadel, 1984)? It is obvious that much more research is needed to flesh out the answers to these questions. However, it has become clear that obtaining answers to questions such as these is crucial to a conceptualization of object representation in infancy.

THE EARLY REPRESENTATIONAL SYSTEM: SOME SUGGESTIONS

At this point it may be helpful to place the individuation results we have described within a broader conceptual framework. We propose that, within the context of physical events, four basic properties of objects are represented: spatiotemporal, mechanical, featural, and functional (see Meltzoff & Moore, 1998, for a related idea). These various object properties are probably encoded and analyzed by different cognitive systems. *Spatiotemporal* information includes information about an object's location, path of motion, or speed of motion. *Mechanical* properties of objects specify how objects move about in the world and the nature of their interactions. In any event involving more than a single object, of primary importance to the physical reasoning system is the relation between objects, whether it involves static states (e.g., on top of, underneath, behind, inside) or active states (e.g., repels, launches, passes behind, moves inside). Hence, mechanical information is crucial to the process of identifying events as belonging to a particular physical category. We have already discussed the importance of event categorization: How an event is categorized will determine the variables that infants bring to bear when reasoning about the event (Baillargeon, 1995, 1998; Baillargeon et al., 1995). *Featural* properties include information such as the size, shape, pattern, and color of an object. We point out that although we have focused here on features that are processed by the visual system, it is most certainly the case that object properties that are not visual in nature are also included in infants' object representations. Finally, *functional* properties specify what objects do and how they are used.

Although these four kinds of properties are distinct, infants' interpretation of events will quite naturally involve their integration. For example, it may be the case that the distinction between animate and inanimate object motion, which infants appear to make at an early age (e.g., Spelke, Phillips, & Woodward, 1995), requires an analysis of the spatiotemporal properties (e.g., whether the path of motion was predictable) and the mechanical properties (e,g., energy source) of the object. In addition, object properties are often intricately related, and it is possible for one object property to be embedded in another object property. To illustrate, embedded within the analysis of object function, by necessity, is information about the mechanical properties of the object. "Inside of" is a mechanical notion: the ability to contain is described by the relation of the object parts to the exterior world. However, the ability to contain is not a functional property. A container takes on function only when it holds a substance.

We would also like to make clear that, although the research presented here focuses on infants' use of information gained through the visual modality, we do not believe that object individuation is a process unique to the visual system. In fact, the idea that infants' representations are both rich and flexible in their content would lead one to predict that infants would demonstrate the ability to use information acquired through other modalities to reason about individuals.

We are currently testing this prediction by examining infants' ability to individuate objects using auditory information. In one experiment, Wilcox, Tuggy, and Napoli (2001) for example, investigated 4.5- and 7.5-month-old infants' sensitivity to two kinds of auditory information: natural and artificial sounds (Walker-Andrews, 1994). *Natural* sounds are produced in accordance with the structure and the substance of an object and are unique to that object (e.g., the sound a jar of marbles makes when it is shaken or the sound of a wooden ball as it hits a solid surface). In contrast, *artificial* sounds are neither naturally occurring nor intrinsic to an object (e.g., the sounds electronic toys make or tones produced by a music box). Infants were presented with an event in which they heard two different sounds, separated by a temporal gap from behind a screen. The screen was then lowered to reveal a single object (i.e., a papiér-maché egg) on the platform. When the sounds were natural (i.e., produced by shaking a papiér-maché egg filled with either uncooked rice or small bells), the infants responded as if they had concluded that two objects were present in the event and were surprised to see only one when the screen was lowered. In contrast, when the sounds were artificial (e.g., tones, produced by an electronic keyboard, that differed in pitch and timbre) the infants responded as if they had failed to draw a conclusion about the number of objects present in the event. Additional experiments are currently underway to examine the nature and development of this ability. For example, when do infants first use artificial sounds to individuate objects? Can young infants be primed to attend to artificial sounds (just like they can be primed to attend to surface features)? Why are some sounds more salient than others? Do infants assume that two identical sounds, heard in succession, are produced by a single object?

Now consider how the framework just outlined could be used to explain and predict how object properties are processed, linked together, and stored in short-term memory. It is possible that, when viewing physical events, infants form something akin to "object folders." These are similar to object files in that they are cognitive structures that contain information about objects. They are different from object files in that they include more than just the spatiotemporal and featural properties of objects; they also include the mechanical and functional properties of objects. We would guess that, initially, infants' object folders are limited in what they contain, that they include only information about the spatiotemporal and mechanical properties of objects. If this were the case, then one would predict that early in development (i.e., before age 4.5 months) infants would rely only on spatiotemporal criteria as the basis of object individuation (Xu & Carey, 1996). However, once infants included featural and functional information into their object folders, they would be capable of opening new object folders based on those properties. We have already provided evidence that infants can use featural information to set up distinct object representations. We have also provided evidence that, by at least 4.5 months, functional information plays an important role in infants' object representations. However, can infants use functional information to individuate objects? Meltzoff and Moore (1998) recently suggested that functional descriptors of objects are important to the process of individuation. Although their focus, and the bulk of their data, is on animate objects—people—they presented convincing reasons why the same might hold true for inanimate objects. There is one caveat: Although infants may be capable of including many sources of information into their object representations, this does not mean that they will always draw on this information when attempting to interpret physical events. Whether infants draw on information depends, first, on whether they have identified it as important to their interpretation of that kind of event, and, second, on other information-processing constraints.

Finally, although infants might be capable of drawing on many different sources of information to interpret physical events, they may not necessarily store all of this information together in memory. The result is that, when required to retrieve object representations, infants may access information about one object property (e.g., the trajectory that on object followed or the function in which an object engaged) without accessing information about other properties of the object (e.g., what the object looked like). In fact, as evidenced by the event-mapping experiments, it is quite likely that infants will not bind all of this information together in memory. One factor that determines whether infants will successfully integrate at least one source of information—featural—into their object representations is whether they have successfully identified the simple structure of the event. In the event-mapping experiments we have conducted, the simple structure of the event was spatial in nature (i.e., the trajectory of each object as it moved back and forth behind the screen). However, it is possible that in other types of events the simple structure is not necessarily spatial. Consider, for example, the following event: a ball rolls down a ramp, contacts a stationary ball, and displaces it. Although one could argue that the spatial relations between the objects could be extracted to form a simple structure, the event might be better described by its mechanics (i.e., the displacement of the second ball as caused by the first). In other words, the simple structure of an event may not always be spatial in nature; it might sometimes be mechanical.[5]

[5]Mandler (1992) argued that mechanical notions can be described in terms of their spatiotemporal patterns. Furthermore, infants engage in a perceptual analysis that creates conceptual structure, such as the notion of agency, containment, or support, from spatiotemporal patterns. According to this view, the simple structure of an event would always be spatial in structure. However, we lean toward the view that mechanical notions cannot be easily reduced to spatiotemporal patterns (Leslie, 1994).

CONCLUSIONS

We have presented evidence that young infants can use featural information as the basis for object individuation and that there are interesting and important developmental changes in how and when this information gets used. First, when event-monitoring tasks are used, infants as young as 4.5 months demonstrate the ability to use featural information to individuate objects in occlusion events. However, infants are not equally sensitive to all types of featural information; they are more likely to attend to form than to surface features. The type of information to which infants are most sensitive appears to be constrained both by early sensory experiences and biases inherent to the physical reasoning system. In addition, infants' sensitivity to surface features can be altered by select experiences. Second, although infants demonstrate a certain level of competency at interpreting occlusion events using featural criteria, the task of building representations of events that include both the spatiotemporal and featural properties of objects is far from easy. This is manifested in two different ways. The first is that infants have difficulty representing different-features events in which the objects undergo more complicated trajectories. The second is that infants have difficulty attaching, or binding, featural information to objects. In both cases, making the simple structure of the event clearer improves performance.

Together, these results provide insight into how infants go about building object representations, infants' ability to retrieve and use their object representations, and the nature and content of those representations. It will be a weaving together of what is known about these abilities, and the complex cognitive processes that they embody, that will ultimately lead to a unified model of object representation in infancy.

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