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Object Individuation in Infancy: The Use of Featural Information in Reasoning about Occlusion Events

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Recent findings by Xu and Carey (1996) indicate that, after seeing two distinct objects (e.g., a duck and a ball) emerge on the opposite sides of a screen, 10-month-olds show no surprise when the screen is removed to reveal one (e.g., a duck) as opposed to two objects (e.g., a duck and a ball). The authors took their results to mean that 10-month-olds are unable to use featural information to individuate objects. The present research examined a different interpretation of the results. This interpretation was based on a distinction between *event mapping,* in which infants see a sequence of two distinct events and judge whether the two are consistent, and *event monitoring,* in which infants see a single event and judge whether successive portions of the event are consistent. The present research contrasted infants' performances in event-mapping tasks in which they saw first an occlusion and then a no-occlusion situation (as in Xu & Carey) and in event-monitoring tasks in which they saw only an occlusion situation. It was hypothesized that infants would be more likely to give evidence of correct individuation when tested with the event-monitoring as opposed to the event-mapping tasks. Eight experiments were conducted with infants ages 7.5 to 11.5 months. These experiments yielded two main findings. First, when tested with an event-monitoring task, even 7.5-month-olds give evidence that they can use featural information to individuate the objects involved in an occlusion

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event. Second, when tested with an event-mapping task, even 9.5-month-olds give evidence that they can use featural information to interpret an occlusion event as long as the event is made extremely simple. These findings give weight to the distinction between event mapping and monitoring and more generally begin to shed light on the fundamental processes involved in infants' formation and use of event representations.

As they look about them, infants routinely observe many different types of physical events: for example, they may see a parent pour juice into a cup, stack dishes, or store groceries in a cupboard. Many developmentalists agree that infants build mental *representations* of the physical events that they observe (e.g., Baillargeon, 1998; Leslie, 1994; Mandler, 1997; Spelke, 1994; Xu & Carey, 1996). In recent years, considerable effort has been expended to shed light on the nature of these representations. Some researchers have been concerned with specifying possible innate constraints on infants' event representations (e.g., Leslie, 1994, 1995; Spelke, 1994; Spelke, Breinlinger, Macomber, & Jacobson, 1992). For example, Spelke (1994; Spelke et al., 1992) has proposed a number of physical principles that would from the start constrain how objects move and interact within infants' event representations. Other investigators have focused on the changes that take place within infants' event representations as they accumulate knowledge and experience (e.g., Aguiar & Baillargeon, 1998a,b; Baillargeon, 1998; Kotovsky & Baillargeon, 1994a, in press; Mandler, 1997; Needham, Baillargeon, & Kaufman, 1997). To illustrate, Baillargeon (1994, 1995, 1998; Baillargeon, Kotovsky, & Needham, 1995) has argued that, when learning about physical events, infants identify increasingly refined variables that enable them to predict outcomes more and more accurately over time. Yet other researchers have been interested in specifying how infants go about building representations for specific physical events (e.g., Oakes, 1994; Oakes & Cohen, 1995; Spelke & Kestenbaum, 1986; Spelke, Kestenbaum, Simons, & Wein, 1995; Xu & Carey, 1996). Within this last area of investigation, one fundamental issue that has attracted a great deal of attention over the past few years is that of *object individuation*—how infants determine, when faced with an event, what objects are involved in the event (e.g., Spelke & Kestenbaum, 1986; Spelke et al., 1995; Xu & Carey, 1996). The present research built on these recent experiments and explored object individuation in infants ages 7.5 months and older.

OBJECT INDIVIDUATION

There is evidence that, from a very early age, infants can use simple forms of *spatiotemporal* information to establish what objects—what separate and distinct entities—are involved in an event (e.g., Slater, Johnson, Kellman, & Spelke, 1994; Slater, Morison, Somers, Mattock, Brown, & Taylor, 1990; Spelke & Born, 1982). For example, infants typically view a collection of adjacent, bounded surfaces that moves along a continuous trajectory as a single object moving through space. Furthermore, infants typically perceive noncontiguous collections of surfaces as distinct objects. Use of such spatiotemporal information would lead infants to correctly individuate the objects in many different types of events. To illustrate, consider an event in which a ball rolls toward a large box on an otherwise empty surface. Infants would view the continuously rolling ball as one object and the spatially noncontiguous box as another, separate object.

However, what of events in which spatiotemporal information alone is not sufficient to establish what objects are present? In their daily lives, infants are often confronted with such events. Consider, in particular, the case of *occlusion* events. To return to our example, what if infants now saw the ball disappear behind one end of the box and later reappear from behind the other end? Because of the box's presence, infants could not see whether the ball traced a single, continuous path from one side of the box to the other; hence, they could not determine, based on spatiotemporal information alone, whether the ball that disappeared and the ball that reappeared were one and the same ball.

Occlusion events thus present infants with a special individuation problem: in order to correctly individuate the objects in such an event, infants must establish whether the objects seen on the left and right of the occluder constitute one or two distinct objects. This description brings to the fore the marked parallels between the process of object individuation, as discussed here, and another process that has been extensively studied by developmental researchers, that of object segregation (see Needham et al., 1997, and Spelke & Van de Walle, 1993, for recent reviews). In object segregation tasks involving partly occluded displays, infants must judge whether the surfaces visible on either side of an occluder (e.g., a large green ball protruding to the left and right of a narrow box) constitute one or two distinct objects (e.g., Craton, 1996; Johnson & Nanez, 1995; Kellman & Spelke, 1983; Needham, 1998; Slater et al., 1990, 1994; Spelke, 1990; Termine, Hrynick, Kestenbaum, Gleitman, & Spelke, 1987). Thus, whether faced with events in which objects successively appear on either side of an occluder, or with displays in which surfaces are simultaneously visible on either side of an occluder, infants are confronted with essentially the same task of determining how many objects are present behind the occluder.

Spelke (1982, 1990; Kellman & Spelke, 1983), Needham (1998; Needham & Baillargeon, 1997, 1998), and others have pointed out that adults draw on several types of information when segregating partly occluded displays; the same is true when adults individuate the objects in occlusion events. One type of information we as adults use when interpreting occlusion events is *featural* information: we compare the features (e.g., shape, size, color, and pattern) of the objects on each side of the occluder and typically conclude that one object is present when the features are identical and that two objects are present when the features are different. Thus, based on featural information, we would most likely assume that a single object was involved if we saw a large green ball disappear and reappear from behind a box and that two objects were involved if we saw a large green ball disappear behind a box and a small red ball emerge from behind it.

A second type of information adults use to interpret occlusion events is *physical* information. Adults possess sophisticated knowledge about the lawful ways in which objects can move and interact and bring this knowledge to bear when judging how many objects are involved in occlusion events. For example, if we knew that a narrow tunnel lay hidden behind a box, and we saw a large green ball disappear and reappear from behind the box, we might conclude that two balls were present, one traveling to the left and one to the right of the tunnel, because we would realize that the ball was too large to travel through the tunnel.

A third type of information adults draw on when interpreting occlusion events is *experiential* knowledge, which corresponds to adults' knowledge of what specific objects, or categories of objects, exist in the world. After inspecting a large green ball and realizing that the ball popped open at random intervals to reveal a toy ballerina on a small circular stage, we would not be surprised to see the ball move behind one end of a box and the ballerina appear at the other end; our knowledge of the ball would lead us to perceive this transformation as possible.

Over the past few years, a number of experiments have explored infants' ability to judge, when faced with an occlusion event, how many objects are involved in the event (e.g., Spelke et al., 1995; Xu & Carey, 1996). Most of this research has focused on infants' use of *featural* information. We first review experiments in which the *same* object appeared on both sides of the occluder and then discuss experiments in which *different* objects appeared; the results of these last experiments provided the impetus for the present research.

SAME-OBJECT OCCLUSION EVENTS

Experiments with Young Infants

Spelke et al. (1995) examined whether 4-month-olds assume, when shown an occlusion event in which the same object appears on either side of an occluder, that a single object is involved in the event. The infants were habituated to a suspended cylinder that moved back and forth along a horizontal track whose center was hidden by a wide screen. Following habituation, the screen was removed, and the infants saw a one- and a two-cylinder test event. In the one-cylinder event, a single cylinder moved back and forth along the track. In the two-cylinder event, two identical cylinders moved sequentially along the track; the left cylinder had the same trajectory as the cylinder visible to the left of the habituation screen, and the right cylinder had the same trajectory as the cylinder visible to the right of the habituation screen. The infants were found to look equally at the one- and two-cylinder test events. This negative result was confirmed in a subsequent experiment carried out with a similar procedure (Spelke et al., 1995). The authors concluded that 4-month-olds make no assumption, when they see an object move back and forth behind an occluder, as to whether one or two objects are involved in the event.

However, this conclusion is inconsistent with the results of recent experiments on the development of infants' knowledge about occlusion events (e.g., Aguiar & Baillargeon, 1998a, b; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987). In one experiment, for example, 3-month-olds were habituated to a toy mouse that moved back and forth behind a screen (Aguiar & Baillargeon, 1998a). Following habituation, the infants saw a possible and an impossible test event. These events were similar to the habituation event except that a portion of the screen's midsection was removed to create a large window. In the possible event, the window was located in the screen's upper half; the mouse was shorter than the window's lower edge and thus did not appear in the window when passing behind the screen. In the impossible event, the window was located in the screen's lower half; in this event, the mouse should have appeared in the window but did not in fact do so. The infants looked reliably longer at the impossible than at the possible event. These and control results indicated that the infants (a) believed that a single mouse was involved in the habituation and test events, (b) expected the mouse to appear in the lower but not the upper window, and hence (c) were surprised in the impossible event when this expectation was violated. Had the infants been unsure about the number of mice involved in the habituation and test events, they would have had no reason to be surprised when no mouse appeared in the lower window in the impossible event; the fact that they did show surprise at this event indicates that they assumed that a single mouse was present in the apparatus (see Aguiar & Baillargeon, 1998a).

Thus, whereas the 4-month-olds tested by Spelke et al. (1995) appeared uncertain whether one or two objects were involved in the habituation event, the 3-month-olds tested by Aguiar and Baillargeon (1998a) believed that a single object was involved in the habituation and test events. Aguiar and Baillargeon attributed this discrepancy to the different reasoning processes required in each experiment. First, consider the infants tested by Spelke et al. To be successful, the infants had to compare the one- or two-cylinder test event before them to the habituation event they had seen earlier. This comparison required a relatively complex form of reasoning: the infants had to retrieve a representation of the habituation event, map it onto the test event before them, and judge whether a match existed between them. Aguiar and Baillargeon termed this type of reasoning *event mapping.* Next, consider the infants tested by Aguiar and Baillargeon (1998a; see also Aguiar & Baillargeon, 1998b, Baillargeon & DeVos, 1991, and Baillargeon & Graber, 1987). To correctly respond to each test event, the infants did not have to compare it to the earlier habituation event; they had only to focus on the test event itself.[1] When watching the impossible test event, for example, the infants had only to compare successive segments of the event to realize that the mouse's emergence at the screen's right edge was inconsistent with the mouse's earlier failure to appear in the screen's window. Aguiar and Baillargeon termed this type of reasoning *event monitoring.*

The main difference between event mapping and monitoring, according to Aguiar and Baillargeon (1998a), is that in event mapping infants compare *two* distinct events and judge whether they are mutually consistent, whereas in event monitoring infants reason about a *single* event and judge whether successive portions of the event are mutually consistent. This distinction gives rise to the following question: what leads infants to conclude that they are faced with two distinct events as opposed to a single, ongoing event?

Consider, in particular, the infants tested by Spelke et al. (1995). According to Aguiar and Baillargeon (1998a), the infants regarded each test event as distinct from the habituation event. On what basis did they do so? There were several differences between the habituation and test events, beginning with the fact that they occurred in separate trials. For reasons that will become clear, however, we believe that a crucial difference between the habituation and test events had to do with the removal of the screen: the infants saw first an *occlusion* and later a *no-occlusion* event, and they regarded the two as physically distinct (we discuss possible bases for this judgment in the Conclusion). The infants attempted to retrieve a representation of the occlusion event and map it onto the no-occlusion event—to judge whether the two were consistent—but they faltered in this attempt. In the experiment of Aguiar and Baillargeon, the infants did not need to relate an occlusion and a no-occlusion event in order to succeed: they had only to reason about a single, *occlusion* event.

One further point needs to be made. Many experiments over the past decade have presented young infants with events in which occluders are first introduced and then removed. Some of these experiments were specifically designed to examine young infants' understanding of occlusion events (e.g., Baillargeon, 1987a,b, 1991; Baillargeon & DeVos, 1991; Baillargeon, Graber, DeVos, & Black, 1990; Baillargeon, Spelke, & Wasserman, 1985; Spelke et al., 1992; Wilcox, Nadel, & Rosser, 1996). Other experiments were designed to explore different aspects of infant cognition and used occlusion

[1] This is not to say that the habituation event was of no use to infants; being well-acquainted with the mouse, the screen, the mouse's passage behind the screen, and so on no doubt made it easier for them to focus on and reason about the screen opening during the test trials.

primarily as a methodological convenience (e.g., Simon, Hespos, & Rochat, 1995; Woodward, Phillips, & Spelke, 1993; Wynn, 1992). In all of the experiments cited here, young infants were found to reason successfully about the events they were shown. Such evidence might be taken to cast doubts on the notion that mappings between occlusion and no-occlusion events are difficult for young infants. It should be stressed, however, that in all of the experiments cited above, the infants were given unambiguous *spatiotemporal* information about the number of objects involved in the occlusion event (e.g., the infants saw each test object in its own separate location before the occluder was introduced or they saw the test objects being placed one at a time behind the occluder). In the experiment of Spelke et al. (1995), however, the infants had to use *featural* information to determine how many objects were present behind the screen.

Taken together, the various findings presented in this section suggest the following hypotheses. First, young infants have no difficulty mapping an occlusion onto a no-occlusion situation (i.e., predicting what should be seen when an occluder is removed) as long as they are able to use spatiotemporal information to individuate the objects in the occlusion situation. Second, young infants have difficulty mapping an occlusion onto a no-occlusion situation if they are forced to use featural information to individuate the objects in the occlusion situation. Finally, young infants are equally adept at monitoring an occlusion event (i.e., predicting what should be seen as the event unfolds) irrespective of whether they had to use spatiotemporal or featural information to individuate the objects in the event.

Experiments with Older Infants

Xu and Carey (1996) recently examined 10-month-olds' responses to same-object occlusion events. Like Spelke et al. (1995), they used an event-mapping task to assess the infants' responses: the infants saw an occlusion and then a no-occlusion situation and judged whether the two were consistent. In one experiment, the infants had to use spatiotemporal information and, in another experiment, featural information, to individuate the objects in the occlusion situation.[2] Xu and Carey reported positive results in the first but not the second experiment. This last finding was identical to that of Spelke et al. and suggested that, at 10 months of age, infants still fail at an event-mapping task when the objects in the occlusion situation must be individuated on the basis of featural as opposed to spatiotemporal information. However, close examination of the experiments conducted by Xu and Carey casts doubts on this conclusion.

[2] The two experiments described here respectively correspond, in Xu and Carey (1996), to Experiment 1 (discontinuous movement condition) and Experiment 3 (same condition). We thank Fei Xu for generously providing the additional means included in our discussion of these experiments.

The infants in the first experiment received introductory trials in which two screens were lowered from above to the apparatus floor and then turned aside to reveal either one cup or two identical cups (the objects were lowered on hidden shelves at the back of the screens and were surreptitiously deposited on the apparatus floor); each outcome was shown on two trials for a total of four trials. These trials were followed by four test trials. At the start of each test trial, two screens were again lowered from above to the apparatus floor. Next, an object (e.g., a duck) moved from behind the left screen to the left wall of the apparatus and then returned behind the screen; another, identical object then moved from behind the right screen to the right apparatus wall and then returned behind the screen. The process was repeated until the infants had observed multiple emergences from each screen. At that point, the screens were turned aside to reveal either one object (e.g., a duck) or two identical objects (e.g., two ducks); each outcome was shown on one trial, and the entire sequence was repeated with new objects (e.g., balls). Reliably different looking patterns were obtained in the introductory and test trials: the infants tended to look equally at the one-object (M = 3.8 s) and two-object (M = 4.7 s) introductory displays, but looked reliably longer at the one-object (M = 9.3 s) than at the two-object (M = 7.5 s) test display. These data suggested that the infants (a) inferred, upon observing that no object appeared between the screens during the test trials, that two objects were involved in the trials and (b) were surprised when the screens were removed to reveal a single object.

In the second experiment, Xu and Carey (1996) presented 10-month-olds with introductory and test trials identical to those in the first experiment, with two exceptions: the two screens were replaced with a single wide screen, and additional emergences were included in the test trials to give the infants greater opportunity to encode the object's featural properties. The infants tended to look equally at the one-object (M = 6.3 s) and two-object (M = 6.3 s) introductory displays, but looked reliably longer at the two-object (M = 7.1 s) than at the one-object (M = 4.8 s) test display. These results suggested that the infants (a) assumed that a single object was moving back and forth across the apparatus during the test trials and (b) were surprised when the screen was removed to reveal two objects. However, Xu and Carey proposed a different interpretation of their results, based on data obtained in a baseline condition. The infants in this condition received four introductory trials, as before (e.g., one cup, two cups, two cups, one cup). Next, the infants received four test trials similar to those in the experimental condition except that the objects never emerged from behind the screen; the screen was simply lowered from above and then turned aside to reveal the one- or two-object test display (e.g., one duck, two ducks, two balls, one ball). Comparison of the baseline condition test data (two-object display, M = 11.1 s; one-object display, M = 10.6 s) and the experimental condition test data (two-object display, M = 7.1 s; one-object display, M = 4.8 s) revealed no reliable difference. Xu and Carey took this negative result (and additional results discussed in the next section) to suggest that 10-month-old infants do not use featural information to reason about the identity of objects that move in and out of view; that is, infants do not conclude, when seeing a duck move back and forth behind a screen, that one duck, rather than two ducks, is involved in the event.

However, it is doubtful whether such a conclusion is warranted. As we just saw, this conclusion was based on the fact that no reliable difference was found between the experimental and baseline infants' test data. Two points need to be considered. First, it is not clear why the experimental infants' test data were not simply compared to their introductory data, as was done in the first experiment. Such a comparison would have yielded a reliable interaction (Xu, personal communication), thereby providing evidence that the experimental infants in the second experiment assumed that a single object was moving back and forth behind the screen.

Second, one might question the comparison in the second experiment of the baseline and experimental test data. The infants in the baseline condition saw one or two cups for four introductory trials and one or two novel objects (e.g., ducks and balls) for four test trials. During the test trials, the baseline infants looked reliably longer overall ($M = 10.8$ s) than did the experimental infants ($M = 6.0$ s), suggesting that the baseline infants were captured by the novelty of the test objects relative to the introductory objects. Recall that unlike the experimental infants, the baseline infants did not see multiple emergences of the test objects and so had little opportunity to habituate to their novelty. The discrepancy in the mean duration of the experimental and baseline infants' test responses made it more difficult statistically to detect the difference in the experimental infants' reactions to the one- and two-object test displays.

According to the preceding analysis, the results of Xu and Carey (1996) indicate that, by 10 months of age, infants can use both spatiotemporal information (first experiment) and featural information (second experiment) to individuate the objects in same-object occlusion events. This last result is consistent with those obtained by Baillargeon and her collaborators with younger infants (Aguiar & Baillargeon, 1998a,b; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987). The results of Xu and Carey extend these findings, however, because they were obtained with a different task: whereas Xu and Carey presented their infants with an event-mapping task (in each test trial, the infants saw first an occlusion and then a no-occlusion situation), Baillargeon and her colleagues used event-monitoring tasks (in each test trial, the infants saw only an occlusion situation). The data of Xu and Carey can thus be taken to suggest that, by 10 months of age, infants give evidence that they can use featural information to individuate the objects in same-object occlusion events, even when tested with an event-mapping task.

DIFFERENT-OBJECTS OCCLUSION EVENTS

In addition to examining 10-month-olds' responses to same-object occlusion events, Xu and Carey (1996) also examined 10- and 12-month-olds' responses to different-objects occlusion events.[3] The design of this experiment was similar to that of the experiments described in the previous section and again made use of an event-mapping task. The infants first received four introductory trials in which they saw one or two objects (e.g., bunny; bunny and basket; truck; truck and camel). Next, the infants saw four test trials. At the start of each trial, one object (e.g., a ball) moved from behind the left edge of a wide screen to the left wall of the apparatus and then returned behind the screen; a different object (e.g., a bottle) then moved from behind the right edge of the screen to the right apparatus wall and then returned behind the screen. The process was repeated until the infants had observed multiple emergences of each object. At that point, the screen was turned aside to reveal either one object (e.g., a ball) or two distinct objects (e.g., a ball and a bottle); the infants saw the one-object display in one trial and the two-object display in another trial, and the entire sequence was repeated with two new objects (e.g., a cup and a book).

The 12-month-olds looked reliably longer at the two- than at the one-object display during the introductory trials, but tended to look equally at the two displays during the test trials. These test results suggested that (a) the infants inferred, based on 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-object test display (a preference suggested by the introductory data), resulted in equal looking times for the two test displays.

In contrast to the 12-month-olds, the 10-month-olds looked reliably longer at the two- than at the one-object display during both the introductory and test trials. Xu and Carey (1996) took these results to suggest that (a) the infants 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- nor the two-object test display surprising; and (c) the infants' test responses reflected only their intrinsic preference for the two-object test display (a preference suggested by the introductory 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 gave evidence that they recognized that two distinct objects were present only when they were shown the two objects simultaneously at the start of the test trials—in other words, only when they were

[3] The experiment described here corresponds to Experiment 5 in Xu and Carey (1996).

able to use spatiotemporal as opposed to featural information to individuate the objects. The infants who were given spatiotemporal information, like the 12-month-olds discussed above, tended to look equally at the one- and two-object test displays, suggesting that their surprise at the one-object display interacted with and effectively cancelled their preference for the two-object display.

Based on their 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, Xu and Carey speculated that infants aged 10 months or less lack specific object concepts such as ball and duck: for it is 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. Membership in everyday object categories depends largely on featural information; how could an infant who was unable to use featural information to individuate objects be successful in forming such categories?

However, there are reasons to doubt the conclusion that infants less than 12 months of age cannot use featural information to individuate objects. Xu and Carey (1996) drew this conclusion because they assumed that the 10-month-olds in their experiments (a) failed to correctly interpret *both* the same-object and the different-objects occlusion events they were shown and thus (b) remained agnostic in the face of *both* featural similarities and featural differences. As was discussed in the previous section, however, we are not convinced that the 10-month-olds tested by Xu and Carey failed to correctly interpret the same-object occlusion events they were shown; our own analysis suggested that the infants attended to the featural similarities between the objects on each side of the screen and concluded that a single object was present.

Why did the 10-month-olds tested by Xu and Carey (1996) fail to give evidence that they correctly interpreted the different-objects occlusion events they were shown? If this failure could not be attributed to a fundamental inability to use featural information to individuate objects—since the infants succeeded when presented with same-object occlusion events—how else could it be explained? Our intuition was it was tied to the fact that the infants were tested with an event-mapping task. We saw in the previous section that, when shown same-object occlusion events, infants give evidence that they correctly interpret the events sooner when tested with an event-monitoring (Aguiar & Baillargeon, 1998a,b; Baillargeon & DeVos, 1991) as opposed to an event-mapping task (Spelke et al., 1995; Xu & Carey, 1996). It seemed possible that, even after infants begin to show competence at event-mapping tasks and succeed with same-object occlusion events, this competence remains initially fragile and is easily overwhelmed by increases in task complexity, such as increases in the number of objects involved in the events.

These speculations led to two experimental predictions. First, infants might be more likely to give evidence that they correctly interpret different-objects occlusion events if tested with an event-monitoring as opposed to an event-mapping task. Second, infants might succeed with different-objects occlusion events, even when assessed with an event-mapping task, if the events were made extremely simple. These two predictions were examined in the present research.

THE PRESENT RESEARCH

The evidence presented in the preceding sections can be summarized as follows. First, infants find event-mapping tasks in which they are asked to relate an occlusion and a no-occlusion situation (Spelke et al., 1995) more difficult than event-monitoring tasks in which they are asked to reason about only an occlusion situation (Aguiar & Baillargeon, 1998a,b; Baillargeon & DeVos, 1991). Second, event-mapping tasks appear to be challenging mainly when infants must rely on featural information (Spelke et al., 1995), as opposed to spatiotemporal information (e.g., Simon et al., 1995; Woodward et al., 1993; Wynn, 1992), to individuate the objects in the occlusion situation. Third, when given an event-mapping task and forced to use featural information to individuate the objects in the occlusion situation, infants succeed with same-object occlusion events at some point between 4 and 10 months of age (Spelke et al., 1995; Xu & Carey, 1996) and with different-objects occlusion events at some point between 10 and 12 months of age (Xu & Carey, 1996).

The present research built on these initial findings. Eight experiments were conducted with infants ages 7.5 to 11.5 months. The experiments focused primarily on infants' ability to use featural information to interpret different-objects occlusion events. Experiments 1 and 2 sought to confirm Xu and Carey's (1996) results and examined whether 11.5-month-olds, but not 9.5-month-olds, would succeed at an event-mapping task. Experiments 3, 4, 5, and 6 investigated whether 9.5- and 7.5-month-olds would perform better when tested with an event-monitoring as opposed to an event-mapping task. Finally, in Experiments 7 and 8, we began to explore whether 9.5-month-olds would be successful if given an event-mapping task involving very simple events.

To anticipate, the results of our experiments were generally positive, suggesting that (a) when tested with an event-monitoring task, even 7.5-month-old infants give evidence that they can use featural information to interpret different-objects occlusion events and (b) when tested with an event-mapping task, even 9.5-month-old infants give evidence that they can correctly interpret different-objects occlusion events as long as the events are made extremely simple. These findings, together with those presented in the Introduction, give weight to the distinction between event monitoring and event mapping and more generally begin to shed light on the fundamental processes involved in infants' formation and use of event representations. We return to these issues in the Conclusion.

EXPERIMENT 1

Xu and Carey (1996) found that 12- but not 10-month-olds could use featural information to correctly interpret different-objects occlusion events. Experiments 1 and 2 attempted to replicate these findings. Infants ages 11.5 months (Experiment 1) and 9.5 months (Experiment 2) were tested with an event-mapping task similar to that devised by Xu and Carey (1996) with one important difference. To circumvent infants' baseline preference for displays composed of two different objects over displays containing a single object, only one test display was used in Experiment 1 and 2, and this display contained a single object.

The infants were assigned to a ball–box or a ball–ball condition (see Fig. 1). The infants in the *ball–box* condition saw a test event composed of an initial and a final phase. During the initial phase, the infants saw a ball move behind the left edge of a 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, the infants saw the ball resting alone behind the screen. 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. Prior to the test trials, the infants in the box–ball and ball–ball conditions received familiarization trials designed to acquaint them with the test objects and their trajectories. These trials were identical to the test trials with one exception: when the screen was lowered, a second, shorter screen was revealed that hid the area behind the first screen.

Our reasoning was as follows. If 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, then they should find this display surprising. In contrast, if the infants in the ball–ball condition (a) were led by the featural similarities between the balls seen on either side of the screen to conclude that they were one and the same ball and (b) perceived no discrepancy between their representation of the initial phase of the event and the display shown in the final phase of the event, then they should *not* find this display surprising. Because infants' surprise at a display typically manifests itself by prolonged attention to the display (e.g., Bornstein, 1985; Spelke, 1985),

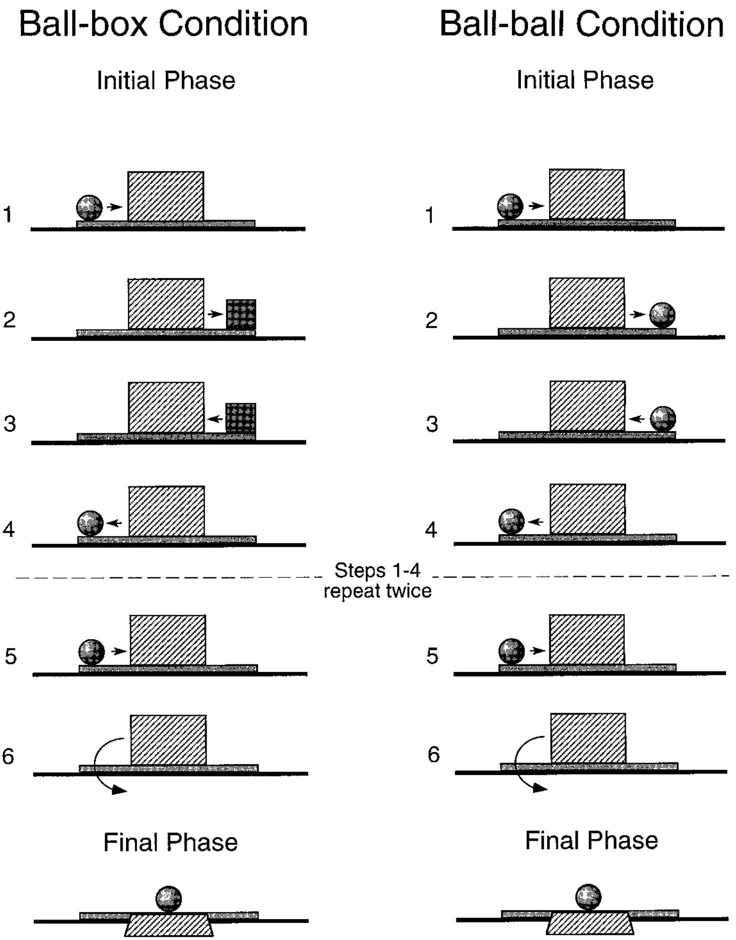

FIG. 1. Schematic drawing of the test events in the ball–box and ball–ball conditions of Experiments 1 and 2.

we predicted that the infants in the ball–box condition, if surprised, would look reliably longer than those in the ball–ball condition.

Method

Subjects

Subjects were 12 healthy full-term infants, 6 male and 6 female (M = 11 months, 11 days; range = 11 months, 3 days to 11 months, 21 days). Three additional infants were tested but eliminated; they failed to complete at least two valid test trials, two because of procedural problems and one because of experimenter error. Six infants were randomly assigned to the ball–box condition (M = 11 months, 8 days) and six to the ball–ball condition (M = 11 months, 13 days).

In this and all subsequent experiments, the infants' names were obtained from birth announcements in the local newspaper. Parents were contacted by letters and follow-up phone calls. They were offered reimbursement for their travel expenses but were not compensated for their participation.

Apparatus

The apparatus consisted of a wooden cubicle 182 cm high, 100 cm wide, and 42 cm deep. The infant sat facing an opening 41 cm high and 94 cm wide in the front wall of the apparatus. The floor of the apparatus was covered with cream-colored contact paper, and the side and back walls were covered with patterned contact paper. A platform 1.5 cm tall, 60 cm wide, and 19 cm deep and covered with patterned contact paper lay 4.5 cm from the back wall, centered between the left and right walls; a 6-cm-wide piece of light blue flannel lay lengthwise down the center of the platform.

The screen used in the familiarization and test events was 30 cm wide and 20 cm high and was mounted on two metal clips positioned 8.5 cm on either side of the center of the platform. The clips were attached to a wooden dowel 92 cm long and 1 cm in diameter that lay on the apparatus floor directly in front of the platform. The left end of the dowel was inserted into a metal ring at the end of the platform; its right end exited the apparatus through a small hole in the right wall. By rotating the dowel's right end (out of the infants' view), an experimenter could lower the screen to the apparatus floor. The second, shorter screen that was placed behind the first screen in the familiarization event was 30 cm wide and 14 cm high; metal legs attached to the shorter screen slid under the platform and kept the screen upright. Both screens were made of blue cardboard and covered with clear contact paper. A metal call bell was used to signal the lowering of the screen in each familiarization and test event.

The infants in the ball–box condition saw two test objects: a ball and a box. The ball was 10.25 cm in diameter, made of styrofoam, and painted green with evenly spaced red, blue, and yellow dots. The ball had a thin wooden stick (not visible from the infants' viewpoint) attached to its back that exited through a slit in the back wall. This slit was 2 cm high and 48 cm wide and was located 7 cm above the apparatus floor; the slit was partially concealed by a 11 × 60 cm white fringe. By moving the ball's stick along the slit, an experimenter could move the ball left and right along the platform.

The box was 11.75 cm square, made of cardboard, covered with red felt, and decorated with evenly spaced silver thumbtacks. The box was open on its left side and also had an open channel in its back. After it moved behind the screen, the ball entered the box through its left open side; the ball's stick protruded through the channel at the back of the box and was used to move the box. The box was first rotated clockwise so that its open side faced down; the box could then be moved to the right of the screen. After it returned behind the screen, the box was rotated counterclockwise and the ball was free to emerge from the box's open side. Although it was not necessary in Experiments 1 and 2 to have the ball move inside the box (i.e., the ball and box could have stopped next to each other behind the screen), this arrangement was essential in Experiments 3 and 4, as will be seen, and for the sake of simplicity was used throughout.

To equate as much as possible the procedures used in the ball–box and ball–ball conditions, a ''fake'' box was placed behind the screen in the ball–ball condition. This box was 11.75 cm square, made of light weight metal, and covered with red felt. The fake box had two open sides (right and left) and an open channel in the back so that the ball and its attached stick could move through the box. The use of the fake box helped ensure that any noise cues associated with the lifting and lowering of the box in the ball–box condition would also be present in the ball–ball condition.

A muslin-covered frame 61 cm high and 100 cm wide was lowered in front of the opening in the front wall of the apparatus at the end of each trial. Two wooden frames, each 182 cm high and 69 cm wide and covered with yellow cloth, stood at an angle on either side of the apparatus. These frames isolated the infants from the experimental room. In addition to the room lighting, two 20-watt fluorescent bulbs 59 cm long were attached inside the front wall of the apparatus.

Events

Three experimenters worked together to produce the familiarization and test events. The first wore a cream-colored glove and moved the ball and box. The second rang the call bell and lowered the screen. The third surreptitiously removed the box from the apparatus before the screen was lowered. The numbers in parentheses indicate the time taken to produce the actions described. A metronome ticked softly once per second to help the experimenters adhere to the events' scripts.

Ball–box condition. At the start of the *initial phase* of the familiarization event shown in the ball–box condition, the ball stood with its center 6 cm from the left edge of the platform. The screen stood centered in front of the platform, with the shorter screen behind it. The box was centered on the platform behind the two screens. After a 1-s pause, the ball moved behind the screen and entered the box, which was quickly rotated (2 s). The box then emerged from behind the screen and moved to the right until its center was 6 cm from the right edge of the platform (2 s). After a 1-s pause, the box returned to its original position behind the screen and was again quickly rotated (2 s). The ball then emerged from the box and returned to its starting position at the left edge of the platform (2 s). When in view, the ball and box moved at a speed of about 12 cm/s; when out of view, the objects were moved slightly faster to allow time for the box's rotation.

The 10-s event cycle just described was repeated twice. Next, the ball paused once again at the left edge of the platform (1 s) and then moved to the right until it was centered behind the screen (2 s) (the third experimenter reached through a hidden opening in the back wall of the apparatus and surreptitiously removed the box after its last disappearance behind the screen). At this point, the second experimenter rang the call bell and lowered the screen to the apparatus floor (1 s), ending the initial phase of the event.

The initial phase of each familiarization event thus lasted about 24 s. During the *final* phase of the event, the infants simply saw the second, shorter screen—revealed when the first screen was lowered—standing on the platform.

The test event shown in the ball–box condition was identical to the familiarization event except that the shorter screen was absent. When the screen was lowered, the ball was revealed resting at the center of the platform.

Ball–ball condition. The familiarization and test events shown in the ball–ball condition were identical to those in the ball–box condition, with two exceptions. First, the ball, rather than the box, emerged to the right of the screen. Second, to prevent observers from distinguishing between the ball–box and ball–ball events on the basis of any faint noise cues associated with the lifting and lowering of the box in the ball–box condition, the fake box was used. After moving behind the screen, the ball entered the fake box, which was then quickly lifted and lowered (to mimic the box's rotation in the ball–box condition); the ball then exited the fake box through its other open side.

Procedure

The infant sat on a parent's lap centered in front of the apparatus. The infant's head was approximately 78 cm from the objects on the platform. The parent was asked not to interact with the infant while the experiment was in progress and to close his or her eyes during the test events.

Each infant participated in a two-phase procedure that consisted of a familiarization and a test phase. During the *familiarization* phase, the infants saw the familiarization event appropriate for their condition in three successive trials. Looking time during the initial and final phase of each trial was monitored separately. The final phase of each trial ended when the infant either (a) looked away for 2 consecutive seconds after having looked for at least 4 cumulative seconds or (b) looked for 30 cumulative seconds without looking away for 2 consecutive seconds. During the *test* phase, the infants saw the test event appropriate for their condition on four successive trials. The criteria for ending the final phase of each test trial were the same as for the familiarization trials.

The infant's looking behavior was monitored by two observers who watched the infant through peepholes in the cloth-covered frames on either side of the apparatus. The observers were not told, and could not determine, to which condition each infant was assigned.[4] Each observer held a button connected to a DELL computer and depressed the button when the infant attended to the events. The looking times recorded by the primary observer were used to determine when a trial had ended. Each trial was divided into 100-ms intervals, and the computer determined in each interval whether the two observers agreed on the direction of the infant's gaze. Interobserver agreement during the final phase of each test trial was calculated for each trial on the basis of the number of intervals in which the computer registered agreement out of the total number of intervals in the trial. Agreement averaged 93% per test trial per infant.

One of the 12 infants in the experiment failed to contribute a full set of four test trials to the data analyses; this infant completed only two test trials, because of procedural problems. Infants in this and in the next experiment were included in the data analyses as long as they had completed at least two valid test trials.

Preliminary analysis of the mean looking times of the infants in the ball–box and ball–ball conditions during the final phases of the test trials revealed no significant Sex × Condition interaction, $F(1, 8) = 0.39$; the data were therefore collapsed across sex in subsequent analyses.[5]

Results

Familiarization Trials

The infants' looking times during the final phases of the three familiarization trials were averaged and compared by means of a one-way analysis of variance (ANOVA) with Condition (ball–ball versus ball–box) as a between-subjects factor. The main effect of condition was not significant, $F(1, 10) = 0.44$, indicating that there was no reliable difference between the mean looking times of the infants in the ball–box ($M = 11.5$ s, $SD = 4.8$) and ball–ball ($M = 9.8$ s, $SD = 4.3$) conditions.

Test Trials

The infants' looking times during the final phases of the four test trials (see Fig. 2) were averaged and analyzed in the same manner as the familiar-

[4] The infants in Experiments 1, 2, 7, and 8 were all presented with test events in which a ball or a ball and box appeared on either side of a screen. For 35 of the 52 infants tested in these experiments, the primary observer was asked at the end of the test session whether the infant had seen the same object or different objects on the two sides of the screen. The primary observer guessed correctly for only 19 of the 35 infants, a performance not significantly different from chance (cumulative binomial probability, $p > .05$).

[5] Because of the small number of infants in each Sex × Condition (ball–box or ball–ball) cell ($n = 3$), this analysis needs to be interpreted with caution. The same caveat applies to the other sex analyses in the paper, all of which yielded negative results.

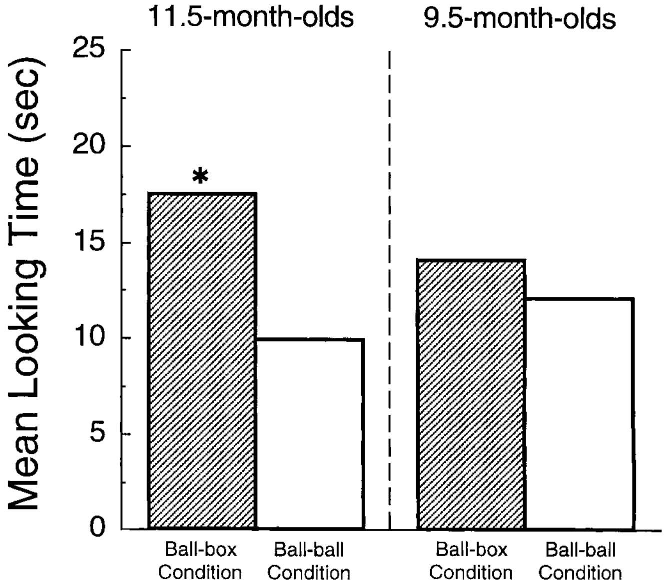

FIG. 2. Mean looking times of the infants in Experiments 1 and 2 during the final phase of the test events.

ization trials. There was a significant main effect of condition, $F(1, 10) = 10.41$, $p < .01$, indicating that the infants in the ball–box condition ($M = 17.5$ s, $SD = 5.0$) looked reliably longer than did the infants in the ball–ball condition ($M = 9.9$ s, $SD = 2.7$).

Discussion

During the final phases of the familiarization trials, when the shorter screen was present, the infants in the box–ball and ball–ball conditions tended to look equally. In contrast, during the final phases of the test trials, when the ball was revealed alone on the platform, the infants in the ball–box condition looked reliably longer than those in the ball–ball condition. Together, these results suggest that the infants in the ball–box condition (a) assumed, based on the featural differences between the ball and box, that they were 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: they were surprised to see only the ball when the screen was lowered. In contrast, the infants in the ball–ball condition (a) were led by the featural similarities between the balls seen on either side of the screen to conclude that they were one and the same ball and (b) recognized that their representation of the initial phase of the event was consistent with the display shown in the final phase of the event.

The positive results of Experiment 1 replicate those obtained by Xu and Carey (1996) with their 12-month-old subjects. Having demonstrated that our method was successful with these older infants, we next tested younger, 9.5-month-old infants. In light of the results obtained by Xu and Carey with their 10-month-old subjects (recall that these infants were not surprised, after watching a different-objects occlusion event, to see a single object behind the screen), we expected that the 9.5-month-olds in Experiment 2, in contrast to the 11.5-month-olds in Experiment 1, would look equally during the final phases of the ball–box and ball–ball test events.

EXPERIMENT 2

Method

Subjects

Subjects were 12 healthy full-term infants, 6 male and 6 female (M = 9 months, 19 days; range = 9 months, 11 days to 10 months, 0 day). One additional infant was tested and eliminated because he looked the maximum of seconds allowed (30 s) on most trials. Six infants were randomly assigned to the ball–box condition (M = 9 months, 19 days) and six to the ball–ball condition (M = 9 months, 19 days).

Apparatus, Events, and Procedure

The apparatus, events, and procedure in Experiment 2 were identical to those in Experiment 1. Interobserver agreement during the final phases of the test trials averaged 92% per trial per infant. Two infants contributed fewer than four test trials to the data analyses; both infants completed only three test trials, one because of fussiness and one because of experimenter error. Preliminary analysis of the mean looking times of the infants in the ball–box and ball–ball conditions during the final phases of the test trials revealed no significant Sex × Condition interaction, $F(1, 8) = 1.70$, $p > .05$; the data were therefore collapsed across sex in subsequent analyses.

Results

Familiarization Trials

The infants' looking times during the final phases of the three familiarization trials were averaged and analyzed as in Experiment 1. The main effect of condition was not significant, $F(1, 10) = 0.35$, indicating that the mean looking times of the infants in the ball–box (M = 13.4 s, SD = 2.5) and ball–ball (M = 15.0 s, SD = 3.0) conditions did not differ reliably.

Test Trials

The infants' looking times during the final phases of the four test trials (see Fig. 2) were averaged and analyzed as in Experiment 1. No significant difference was found between the mean looking times of the infants in the ball–box (M = 14.1 s, SD = 7.6) and ball–ball (M = 12.1 s, SD = 3.6) conditions, $F(1, 10) = 0.34$.

Discussion

The 9.5-month-olds in the ball–box and ball–ball conditions looked about equally during the final phases of the test trials. This negative finding suggests that the infants in the ball–box condition were *not* surprised to see only the ball when the screen was lowered. The present results are thus consistent with those of Xu and Carey (1996).

As in the experiments of Xu and Carey (1996), the infants in Experiment 2 were tested with an event-mapping task: objects emerged on either side of a screen and then the screen was removed to reveal a single object; the infants thus had to map an occlusion onto a no-occlusion situation and judge whether the two were consistent. As we saw earlier, event mapping may be more difficult for infants than is event monitoring, particularly when they must use featural as opposed to spatiotemporal information to individuate the objects in the occlusion situation. Recall that, when tested with an event-monitoring task, infants as young as 3 months of age give evidence that they correctly interpret same-object occlusion events (Aguiar & Baillargeon, 1998a,b; Baillargeon & DeVos, 1991); when tested with an event-mapping task, however, it is not until some time between 4 and 10 months of age that infants perform successfully with same-object occlusion events (Spelke et al., 1995; Xu & Carey, 1996). This analysis suggested that 9.5-month-olds might succeed with different-objects occlusion events if given an event-monitoring rather than an event-mapping task.

Support for this hypothesis came from positive findings obtained by Needham and her colleagues in experiments on young infants' segregation of partly occluded displays (e.g., Needham, 1998; Needham et al., 1997). The infants in these experiments were presented with a partly occluded display in which similar or dissimilar surfaces were visible on either side of a screen; only featural information could be used to determine how many objects were contained in the display. The infants' interpretation of the display was assessed by means of an event-monitoring task: the infants were presented only with an occlusion situation (the occluder was never removed). To illustrate, in one experiment, 4.5-month-olds received familiarization trials in which they saw a stationary, dissimilar, partly occluded display (Needham, 1998). This display consisted of a yellow cylinder and a tall blue box that protruded from behind the left and right edges, respectively, of a tall narrow screen. Next, the infants received test trials in which a hand grasped the cylinder and moved it back and forth toward and away from the screen. For half of the infants (move-together condition), the box moved with the cylinder; for the other infants (move-apart condition), the box remained stationary. The infants in the move-together condition looked reliably longer than those in the move-apart condition. These and control results indicated that the infants (a) were led by the featural differences between the cylinder and the box to conclude that they were distinct objects and (b) expected the cylinder to move alone and were surprised when it did not. These and related findings (see Needham et al., 1997, for a review) suggest that, when tested with an event-monitoring task, infants as young as 4.5 months of age give evidence that they can use featural information to judge how many objects are present in a similar, or a dissimilar, partly occluded display.

In light of these results, it seemed possible that 9.5-month-olds who were tested with an event-monitoring task would give evidence that they were able to use featural information to judge how many objects were involved in a different-objects occlusion event.

EXPERIMENT 3

In Experiment 3, as in Experiment 2, 9.5-month-olds were presented with a different-objects occlusion event. In contrast to Experiment 2, however, the infants' interpretation of the event was assessed, not by lowering the screen to reveal one of the objects involved in the event, but by means of a width-comparison task: the infants judged whether the screen was sufficiently wide to simultaneously hide the two objects involved in the event.

The infants in Experiment 3 were assigned to either a narrow- or a wide-screen condition (see Fig. 3). During the test trials, the infants in the two conditions saw a ball move behind the left edge of a screen; after a brief interval, a box appeared at the screen's right edge. Next, the box returned behind the screen, and, after another brief interval, the ball returned to its initial position to the left of the screen. This ball–box sequence was repeated continuously until the end of the trial. The only difference between the two conditions had to do with the width of the screen: in the *wide-screen* condition, the screen was sufficiently wide to hide the ball and the box at the same time; in the *narrow-screen* condition, however, the screen was not, so that it should have been impossible for the ball and the box to be simultaneously hidden.

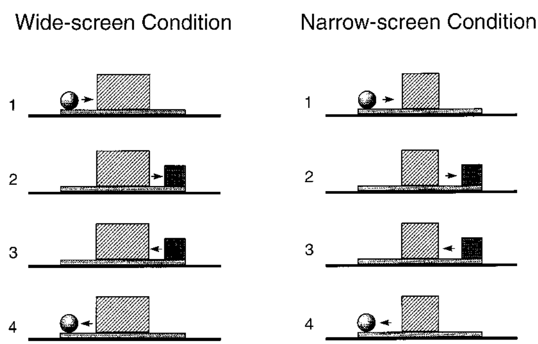

FIG. 3. Schematic drawing of the test events in the experimental narrow- and wide-screen conditions of Experiments 3 and 4.

Prior to the test trials, the infants received familiarization trials designed to acquaint them with the ball and its occlusion. A very wide screen hid the middle and right portions of the platform; the infants simply saw the ball disappear and reappear at the left edge of the screen. Next, the familiarization screen was replaced by the narrow or wide screen, and the infants saw two pretest displays designed to introduce the screen and objects used in the test trials: in one display, the ball lay stationary to the left of the screen, and in the other display, the box lay stationary to the right of the screen.

Our reasoning was as follows. If the infants (a) were led by the featural differences between the ball and box to conclude that they were distinct objects and (b) realized that the combined width of the ball and box relative to that of the screen determined whether the two objects could simultaneously hide behind the screen, then they should be surprised by the narrow- but not the wide-screen test event. The infants in the narrow-screen condition should thus look reliably longer than those in the wide-screen condition.

One potential difficulty with the design of this experiment was that the infants might look longer at the narrow- than at the wide-screen test event simply because of superficial differences between the events (e.g., the infants might have a preference for the narrow over the wide screen). To rule out this possibility, infants were tested in two control conditions identical to the narrow- and wide-screen experimental conditions except that the ball and box were replaced by a *smaller* ball and box (see Fig. 4). The small ball and box could simultaneously fit behind either the narrow or the wide screen. We reasoned that if the experimental infants looked longer at the narrow-screen test event because they preferred the narrow screen, then the control infants should also look longer at the narrow- than at the wide-screen test event. On the other hand, if the experimental infants looked longer at the narrow-screen test event because they were surprised that the ball and box could both hide behind the screen, then the control infants should look

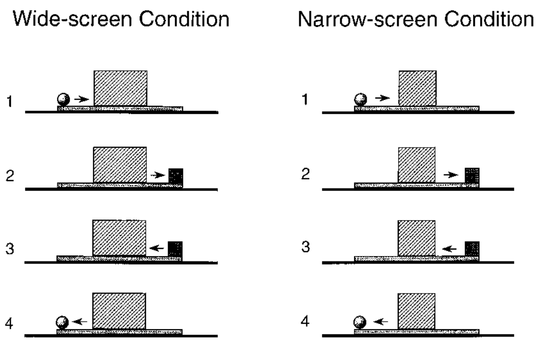

FIG. 4. Schematic drawing of the test events in the control narrow- and wide-screen conditions of Experiments 3 and 4.

equally at the narrow- and wide-screen test events because they should perceive neither event as surprising.

Method

Subjects

Subjects were 24 healthy full-term infants, 12 male and 12 female (M = 9 months, 19 days; range = 9 months, 10 days to 10 months, 2 days). Three additional infants were tested but eliminated; they failed to complete four valid test trials because of experimenter error. Six infants were randomly assigned to each of the four groups formed by crossing the two object conditions (experimental versus control) and the two screen conditions (narrow- versus wide-screen): experimental narrow-screen (M = 9 months, 21 days); experimental wide-screen (M = 9 months, 19 days); control narrow-screen (M = 9 months, 16 days); and control wide-screen (M = 9 months, 18 days).

Apparatus

The apparatus used in Experiment 3 was identical to that in Experiments 1 and 2 with the following exceptions. The screen used in the familiarization trials was 45 cm wide and 20 cm high, made of cardboard, and covered with yellow contact paper. The wide test screen was 30 cm wide and 20 cm high and was identical to the test screen used in Experiments 1 and 2; the narrow test screen was 21 cm wide and 20 cm high. Both test screens were made of blue cardboard and covered with clear contact paper.

The ball and box used in the experimental conditions were the same as in Experiments 1 and 2. The small ball used in the control conditions was 7 cm in diameter and looked identical in color and pattern to the larger ball; the small box was 8 cm high and 8 cm wide and looked identical to the large box except that it was closed on all sides. The small ball was never inserted in the small box, as was the case with the larger ball and box. Because of their sizes, a different system was used to move the small ball and box. A thin stick protruded from the back of each object and was attached to the front leg of a small U-shaped metal piece that was covered with the same contact paper as the back wall. The bottom of the U was covered with felt and fit in a 1-cm gap between the bottom of the back wall and the apparatus floor; the gap was masked with cream-colored cloth. The back leg of the U was located behind the back wall and was moved along a wooden guide to move the object.

Events

Three experimenters worked together to produce the events. The first wore a cream-colored glove and moved the objects, the second manipulated the screens, and the third surreptitiously inserted the box in the apparatus during the familiarization and test events.

Experimental narrow-screen condition. At the start of the familiarization event shown in the experimental narrow-screen condition, the ball lay with its center 6 cm from the left edge of the platform. The familiarization screen stood upright with its right edge against the right edge of the platform, hiding the middle and right portions of the platform.

Each familiarization trial began with a brief pretrial in which the observers monitored the infants' looking at the ball until the computer signaled that the infant had looked for 2 cumulative seconds. At the end of the pretrial, the third experimenter surreptitiously inserted the box through an opening in the back wall of the apparatus (3 s); the box was placed at the center of the platform behind the screen, with its open side facing left (although it was not necessary in Experiments 3 and 4 to have the box secretly introduced in the apparatus—the box could have been there from the start—this step was essential in Experiment 5, as will be seen, and for the sake of uniformity was used here as well). The ball then moved to the right until it reached the center of the platform and entered the box, which was quickly rotated (2 s). The box then moved to the right until its center was 6 cm from the right edge of the platform (2 s). After a 1-s pause, the box returned to the center of the platform, where it was once again quickly rotated (2 s). The ball then emerged from the box, returned to its initial position at the left edge of the platform (2 s), and paused (1 s).

The last 10 s of the event sequence just described were repeated continuously until the trial ended. When in view, the ball and box moved at a speed of about 12 cm/s; when out of view, the objects were moved slightly faster to allow time for the box's rotation.

The infants in the experimental narrow-screen condition saw two pretest displays. In both, the narrow test screen stood upright at the center of the platform, leaving the left portion and (for the first time) the right portion of the platform visible. In the first pretest display, the ball lay with its center 6 cm from the left edge of the platform. In the second pretest display, the box (its open side facing down) rested with its center 6 cm from the right edge of the platform.

The test event shown in the experimental narrow-screen condition was identical to the familiarization event except that the narrow screen was used; the infants saw the ball to the left of the narrow screen and the box to the right.

Experimental wide-screen condition. The familiarization event shown in the experimental wide-screen condition was identical to that in the experimental narrow-screen condition. The pretest displays and test event were also identical, except that the wide test screen was substituted for the narrow test screen.

Control narrow- and wide-screen conditions. The familiarization and test events shown in the control narrow- and wide-screen conditions were similar to those in the experimental narrow- and wide-screen conditions, respectively, with the following exceptions. First, the small ball and box were used. Second, the small box was already in the apparatus, behind the screen, at the start of the events (this modification was made necessary by the mechanism used to move the small box). Third, to prevent observers from using noise cues to distinguish between the experimental and the control conditions, two special steps were taken: first, to simulate any noise made when the larger box was inserted in the apparatus, at the start of each familiarization and test event, an experimenter reached through the hidden opening in the back wall and lifted and lowered the small box; second, to simulate any noise made when the larger box was rotated, during the familiarization and test events, the small box was again lifted and lowered.

The pretest displays shown to the infants in the control conditions were identical to those shown to the infants in the experimental conditions, except that the small ball and box were used. When in position, the center of each small object was 6 cm from the edge of the platform.

Adult Ratings

One discernible problem with the apparatus and events used to implement the design of Experiment 3 had to do with the magnitude of the violation shown in the experimental narrow-screen test event. Because the narrow screen was 21 cm wide, the ball 10.25 cm wide, and the box 11.75 cm wide, the screen was only 1 cm narrower than the ball and box combined; it could be questioned whether even adults could detect such a small violation reliably. However, our own impressions while piloting Experiment 3, as well as informal judgments collected at the time with adult and child visitors to the laboratory, suggested that the violation was not only detectable but that it in fact appeared several times greater than it really was.

To confirm these informal observations, 12 naive adults (6 males, 6 females, $M = 29.8$ years) were shown the experimental narrow- and wide-screen test events. Each event was presented for 30 s and was performed in the manner described above. Half of the subjects saw the narrow-screen event first, and half saw the wide-screen event first. After watching each event, the subjects completed a form in which they were asked questions designed to determine whether they believed that the screen was sufficiently wide to hide the ball and box at the same time during the event. If the subjects indicated that the screen was too narrow to hide the ball and box at the same time, they were asked to mark on a horizontal line how much wider the screen would need to be to hide the two objects together; the left end of the line was labeled ‘‘0 cm’’ and the right end ‘‘15 cm.’’ If the subjects indicated that the screen was sufficiently wide to hide the ball and box at the same time, they were asked to mark on a similar line how much narrower the screen could be and still hide the two objects.

After viewing the narrow-screen event, 10 of the 12 adult subjects ($p < .025$, cumulative binomial probability) indicated that the screen was too narrow to hide the ball and box at the same time. On average, these subjects estimated that the screen needed to be 5.5 cm ($SD = 3.9$) wider to hide the two objects together. After viewing the wide-screen event, 10 of the 12 adult subjects ($p < .025$, cumulative binomial probability) indicated that the screen was sufficiently wide to hide the ball and box at the same time. On average, these same subjects estimated that the screen could be 5.4 cm ($SD = 2.8$) narrower and still hide the two objects (the screen was actually 8 cm wider than the objects).

The results obtained with the adult subjects thus confirmed our initial informal observations. When shown the experimental narrow-screen event, adults readily detect the violation embedded in the event and tend to perceive the violation as greater than it really is. One possible explanation for this finding is that, when watching the event, adults assume that the ball or box, rather than stopping abruptly as soon as it disappears from sight, pursues its trajectory for a short distance behind the screen. Such an assumption would naturally tend to inflate the perception that the screen is too narrow to hide the ball and box at the same time. This explanation brings to mind the evidence in the cognition literature that adults' memory for the orientation or position of a moving object often presents a forward bias—a shift in the direction of the object's real or implied motion (e.g., Freyd, 1993; Freyd & Finke, 1984, 1985; Freyd & Miller, 1992; Hubbard, 1990; Hubbard & Bharucha, 1988; Verfaillie & d'Ydewalle, 1991). Freyd and her colleagues termed this phenomenon ‘‘representational momentum’’ and took it to indicate that adults cannot instantaneously halt the representation of an object's motion (Freyd, 1993). Our adult data seem consistent with such a view and furthermore suggest that momentum effects can be observed not only when adults are remembering a past displacement event but also when they are reasoning about an ongoing occlusion event.

Whatever the ultimate explanation for our adult results, however, the important point remains that the violation shown in the experimental narrow-screen condition was one adults had no difficulty detecting. Experiment 3 examined whether 9.5-month-old infants, too, could detect this violation.

Procedure

The procedure used in Experiment 3 was identical to that in Experiments 1 and 2 with the following exceptions. Each infant participated in a three-phase procedure that consisted of familiarization, pretest-display, and test phases. During the *familiarization* phase, the infants saw the familiarization event appropriate for their condition on two successive trials. Each trial ended when the infant (a) looked away for 2 consecutive seconds after having looked at the event for at least 10 cumulative seconds (beginning at the end of the pretrial) or (b) looked for 60 cumulative seconds without looking away for 2 consecutive seconds.

During the *pretest-display* phase, the infants saw the two pretest displays appropriate for their condition on two successive trials. Each trial ended when the infant (a) looked away for 2 consecutive seconds after having looked at the display for at least 5 cumulative seconds or (b) looked for 30 cumulative seconds without looking away for 2 consecutive seconds.

Finally, during the *test* phase, the infants saw the test event appropriate for their condition on four successive trials. Each trial ended when the infant (a) looked away for 0.5 consecutive seconds after having looked for at least 5 cumulative seconds (beginning after the computer signaled that the infant had looked at the ball for 2 cumulative seconds) or (b) looked for 60 cumulative seconds without looking away for 0.5 consecutive seconds.

The infants' looking behavior was monitored throughout the familiarization, pretest-display, and test trials. Interobserver agreement during the test trials averaged 96% per test trial per infant.[6] Preliminary analyses of the infants' mean looking times during the test trials did not yield a significant Sex × Object Condition (experimental versus control) × Screen Condition (narrow- versus wide-screen) interaction, $F(1, 16) = 0.23$; the data were therefore collapsed across sex in subsequent analyses.

Results

Familiarization Trials

The infants' looking times during the two familiarization trials were averaged and compared by means of a 2 × 2 ANOVA with Object Condition (experimental versus control) and Screen Condition (narrow- versus wide-screen) as between-subjects factors. The Object Condition × Screen Condition interaction was not significant, $F(1, 20) = 1.03$, $p > .05$, indicating that the infants in the different conditions did not differ reliably in their mean looking times during the familiarization trials (experimental narrow-screen condition, $M = 36.5$ s, $SD = 12.7$; experimental wide-screen condition, $M = 37.7$ s, $SD = 20.3$; control narrow-screen condition, $M = 33.5$ s, $SD = 16.8$; control wide-screen condition, $M = 22.4$ s, $SD = 5.9$).

Pretest-Display Trials

The infants' looking times during the two pretest-display trials were averaged and analyzed in the same manner as the familiarization trials. The Object Condition × Screen Condition interaction was again not significant, $F(1, 20) = 0.17$, indicating that the infants in the different conditions did not differ reliably in their mean looking times during the pretest-display trials (experimental narrow-screen condition, $M = 19.3$ s, $SD = 3.3$; experimental wide-screen condition, $M = 18.0$ s, $SD = 5.8$; control narrow-screen condition, $M = 21.1$ s, $SD = 7.9$; control wide-screen condition, $M = 21.8$ s, $SD = 5.7$).

Test Trials

The infants' looking times during the four test trials (see Fig. 5) were averaged and analyzed in the same manner as the familiarization and pretest-display trials. There was a significant main effect of screen condition, $F(1, 20) = 4.95$, $p < .05$, and a significant Object Condition × Screen Condition interaction, $F(1, 20) = 7.97$, $p < .025$. A planned contrast indicated that the infants in the experimental narrow-screen condition looked reliably longer

[6] The infants in Experiments 3, 4, and 6 were all presented with test events in which a ball and box appeared on either side of a wide or narrow screen. For 53 of the 66 infants in these experiments, the primary observer was asked at the end of the test session whether the infant had been assigned to the wide- or the narrow-screen condition. The primary observer guessed correctly for only 29 of the 53 infants, a performance not significantly different from chance (cumulative binomial probability, $p > .05$).

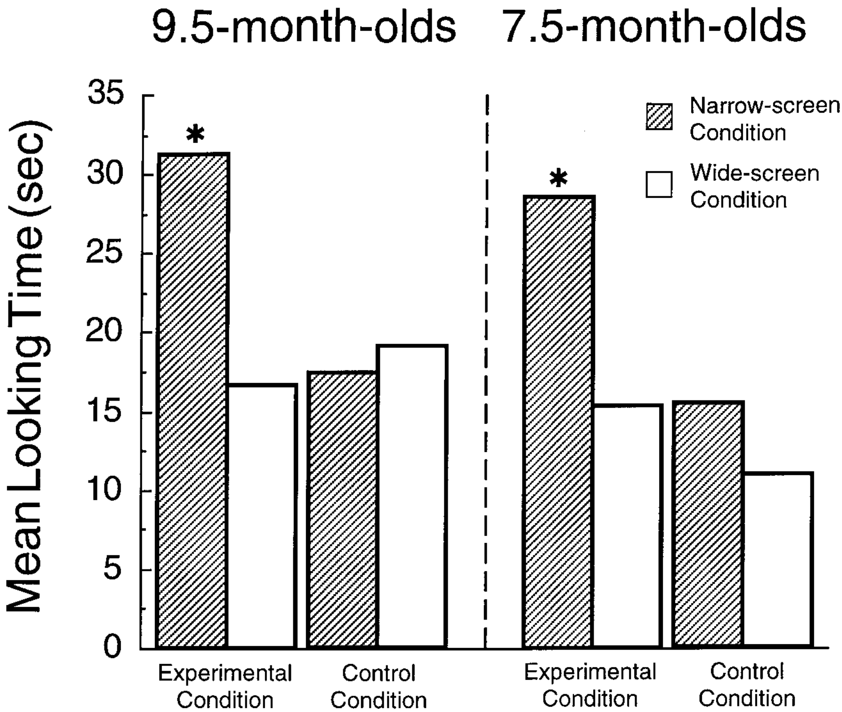

FIG. 5. Mean looking times of the infants in Experiments 3 and 4 at the test events.

(M = 31.2 s, SD = 9.2) than those in the other three conditions, $F(1, 20) = 16.95$, $p < .001$ (experimental wide-screen, M = 16.7 s, SD = 4.0; control narrow-screen, M = 17.4 s, SD = 6.1; control wide-screen, M = 19.1 s, SD = 7.9).

Discussion

The infants in the experimental narrow-screen condition looked reliably longer than those in the experimental wide-screen condition and the control narrow- and wide-screen conditions. These results suggest that the experimental infants (a) were led by the featural differences between the ball and box to conclude that they were distinct objects, (b) compared their combined width to that of the screen and judged that they could simultaneously hide behind the wide but not the narrow screen, and hence (c) were surprised in the experimental narrow-screen test event when the ball and box both hid behind the screen.

The results of Experiment 3 suggest that, when tested with an event-monitoring task, 9.5-month-olds give evidence that they can use featural information to interpret a different-objects occlusion event. Experiment 4 examined whether the positive results of Experiment 3 could be extended to younger, 7.5-month-old infants.

EXPERIMENT 4

Method

Subjects

Subjects were 28 healthy full-term infants, 14 male and 14 female ($M = 7$ months, 15 days; range = 7 months, 0 day to 8 months, 5 days). Two additional infants were tested but eliminated; they failed to complete four valid test trials, one because of experimenter error and one because of equipment failure. Seven infants were randomly assigned to the experimental narrow-screen ($M = 7$ months, 13 days), the experimental wide-screen ($M = 7$ months, 16 days), the control narrow-screen ($M = 7$ months, 14 days), and the control wide-screen ($M = 7$ months, 15 days) conditions.

Apparatus, Events, and Procedures

The apparatus, events, and procedure in Experiment 4 were identical to those in Experiment 3 with two exceptions. First, the infants received six, rather than two, familiarization trials. Second, the objects in the pretest-display trials were placed closer to the screen. In Experiment 3, the objects were always positioned with their centers 6 cm from the end of the platform. This meant that, in the experimental wide-screen condition, the right edge of the ball was 4 cm from the left edge of the screen, and the left edge of the box was 3.5 cm from the right edge of the screen; however, in the other conditions, the distance between the objects and the screen was greater, because the objects and/or the screen were smaller. In Experiment 4, the distance between the objects and the screen was equated across conditions: the large or small ball lay 4 cm and the large or small box 3.5 cm from the screen. It was thought that this change would not only make the conditions more similar, but might also facilitate the infants' comparisons of the widths of the objects and screens.

Interobserver agreement averaged 96% per test trial per infant. Preliminary analyses of the infants' mean looking times during the test trials did not yield a significant Sex × Object Condition × Screen Condition interaction, $F(1, 20) = 1.31$, $p > .05$; the data were therefore collapsed across sex in subsequent analyses.

Results

Familiarization Trials

The infants' looking times during the six familiarization trials were averaged and analyzed as in Experiment 3. The analysis revealed a significant Object Condition × Screen Condition interaction, $F(1, 24) = 4.55$, $p < .05$. A follow-up contrast indicated that the infants in the control wide-screen condition ($M = 31.1$ s, $SD = 6.4$) looked reliably longer than those in the other three conditions, $F(1, 24) = 4.71$, $p < .05$ (experimental narrow-screen, $M = 27.8$ s, $SD = 5.0$; experimental wide-screen, $M = 23.4$ s, $SD = 4.0$; and control narrow-screen, $M = 26.0$ s, $SD = 7.6$). Since the infants in the control wide- and narrow-screen conditions saw exactly the same familiarization event, this result most likely reflects random sampling variation.

Pretest-Display Trials

The infants' looking times during the two pretest-display trials were analyzed as in Experiment 3. The Object Condition × Screen Condition interaction was not significant, $F(1, 24) = 0.26$, indicating that the infants in the different conditions did not differ reliably in their mean looking times during the pretest-display trials (experimental narrow-screen condition, $M = 22.8$ s, $SD = 7.2$; experimental wide-screen condition, $M = 17.4$ s, $SD = 7.0$; control narrow-screen condition, $M = 19.9$ s, $SD = 3.0$; control wide-screen condition, $M = 16.6$ s, $SD = 2.5$).

Test Trials

The infants' looking times during the four test trials (see Fig. 5) were averaged and analyzed as in Experiment 3. The analysis yielded a significant Object Condition × Screen Condition interaction, $F(1, 24) = 5.56$, $p < .05$. A planned contrast indicated that the infants in the experimental narrow-screen condition ($M = 28.5$ s, $SD = 7.9$) looked reliably longer than those in the other three conditions, $F(1, 24) = 8.39$, $p < .01$ (experimental wide-screen, $M = 15.3$ s, $SD = 11.4$; control narrow-screen, $M = 15.4$ s, $SD = 10.9$; control wide-screen, $M = 19.2$ s, $SD = 7.3$).

Further Results

An additional group of 7.5-month-olds (4 males and 3 females, $M = 7$ months, 13 days, range = 7 months, 3 days to 7 months, 29 days) were tested in a condition identical to the experimental wide-screen condition except that the ball and box were *both* present, on either side of the screen, during each pretest-display trial. The infants in this condition thus had explicit spatiotemporal information indicating that the ball and box were separate objects. The infants' looking times during the four test trials were averaged and compared to those of the infants in the original experimental wide-screen condition by means of a one-way ANOVA with Condition (original or modified) as a between-subjects factor. The main effect of condition was not significant, $F(1, 12) = 0.34$, indicating that there was no reliable difference between the mean looking times of the infants in the original ($M = 15.3$ s, $SD = 11.4$) and modified ($M = 18.4$ s, $SD = 8.6$) experimental wide-screen conditions. These results provide support for the conclusion that the infants in the original experimental wide-screen condition (a) inferred that the ball and box were two different objects and (b) realized that the screen was sufficiently wide to hide them both.

Discussion

Like the 9.5-month-olds in Experiment 3, the 7.5-month-olds in Experiment 4 looked reliably longer at the experimental narrow-screen test event than at the experimental wide-screen and the control narrow- and wide-screen test events. These results suggest that the experimental infants (a) concluded, based on the featural differences between the ball and box, that they were distinct objects; (b) understood that the combined width of the ball and box, relative to that of the screen, determined whether they could simultaneously hide behind the screen; (c) judged that the ball and box could both hide behind the wide but not the narrow screen; and hence (d) were surprised in the narrow-screen test event when this last judgment was violated.

The results of Experiment 4 thus confirm and extend those of Experiment 3: they suggest that, when tested with an event-monitoring task, infants as young as 7.5 months of age give evidence that they can use featural information to interpret a different-objects occlusion event.

The results of Experiments 3 and 4 also suggest that, when presented with a different-objects occlusion event, infants ages 7.5 months and older are able to consider whether the occluder is sufficiently wide to hide the two objects simultaneously. Although this ability is tangential to the central issues explored here—it simply provided a convenient means of exploring infants' capacity for individuation—interesting questions can be raised about the nature of the reasoning process that underlies it. For brevity's sake, only two such questions are mentioned here. The *first* is whether the infants in Experiments 3 and 4 used a quantitative or a qualitative strategy to compare the width of the screen to that of the ball and box. In computational models of everyday physical reasoning (e.g., Forbus, 1984), a strategy is said to be quantitative if it requires subjects to encode and use information about absolute quantities (e.g., object A is ''this'' wide, where ''this'' stands for some absolute measure of A's width). In contrast, a strategy is said to be qualitative if it requires subjects to encode and use information about only relative quantities (e.g., object A is wider than object B). Recent experiments indicate that infants ages 6.5 to 8.5 months can reason quantitatively about width or height information in a variety of physical events, including arrested-motion (e.g., Baillargeon, 1987b, 1991), collision (e.g., Kotovsky & Baillargeon, 1994b, cited in Baillargeon, 1995), and containment (e.g., Aguiar & Baillargeon, 1998c) events. This evidence suggests that accounts of the reasoning process used by the infants in Experiments 3 and 4 would not need to be confined to qualitative strategies.

The *second* question concerns the research discussed earlier on representational momentum (e.g., Freyd, 1993; Freyd & Finke, 1984, 1985; Freyd & Miller, 1992; Hubbard, 1990; Hubbard & Bharucha, 1988; Verfaillie & d'Ydewalle, 1991). Do infants, like adults, exhibit representational momentum? Consider, for example, the infants who saw the experimental narrow-screen test event. Presumably, the infants realized within one or two event cycles that the ball came to a stop after it disappeared behind the screen. Did the infants mentally picture the ball as moving some distance behind the screen before coming to a stop? Did they reason, when the box emerged into view, that the space to the right of the ball behind the screen (a quantitative judgment, since it required the infants to represent the width of the ball) was too narrow to have held the entire box? Positive answers to these questions would suggest that infants, like adults, cannot halt represented motions instantaneously. More generally, such results could be taken as evidence that infants' event representations possess some of the same dynamic properties as adults' (Freyd, 1993).

Because these speculations take us away from our main focus on infants' ability to individuate objects in occlusion events, we do not pursue them here. Instead, we return to the conclusion, suggested by the results of Experiments 3 and 4, that infants ages 7.5 months and older give evidence when tested with event-monitoring tasks that they can use featural information to individuate objects. Two alternative interpretations of the results were examined in Experiments 5 and 6.

EXPERIMENT 5

The infants in Experiments 3 and 4 who were tested with a narrow screen responded differently depending on the sizes of the objects used: they looked reliably longer when the large rather than the small ball and box were used. In contrast, the infants in Experiments 3 and 4 who were tested with a wide screen tended to look equally, and equally low, irrespective of the sizes of the objects used. One interpretation for these data was the one presented earlier: the infants realized that the small ball and box could both hide behind the narrow and the wide screens, whereas the large ball and box could both hide behind only the narrow screen. However, an alternative interpretation of the data was that, while the *narrow-screen* infants reasoned in this manner, the *wide-screen* infants did not. Because all of the results obtained with the wide screen were essentially negative (i.e., low looking times across all conditions), it could be argued that the infants were overwhelmed by the wide screen, paid scant attention to the objects that emerged on either side of it, failed to notice the differences between them, and hence looked equally low across conditions.

This alternative account of the wide-screen data was not very plausible: the difference between the widths of the narrow (21 cm) and wide (30 cm) screen was small, as was the difference between the duration of the objects' occlusion in the narrow-screen (about 1.8 s) and wide-screen (about 2.5 s) test events. Given the remarkable robustness of young infants' recognition memory (e.g., Cornell, 1979; Fagan, 1970, 1971, 1974; Lasky, 1980; Martin, 1975; Rose, 1980, 1981), it was difficult to believe that such trivial differences could have had such a dramatic effect. Nevertheless, to examine this alternative interpretation, 7.5-month-olds were tested in Experiment 5 with a procedure identical to that of the experimental wide-screen condition in

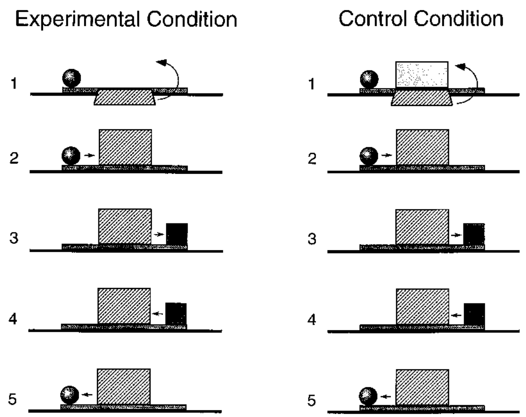

FIG. 6. Schematic drawing of the test events in the experimental and control conditions of Experiment 5.

Experiment 4 with one exception: the wide screen was lowered to the apparatus floor at the start of each familiarization, pretest-display, and test trial, and the infants could see that the area behind the screen was empty; only the ball was present to the left of the screen (see Fig. 6). After a few seconds, the screen was raised, and the trials proceeded exactly as in Experiments 3 and 4. A second group of infants was tested in a control condition that was similar except that a second, shorter screen stood behind the first screen and hid the area behind it.

Our reasoning was as follows. If the infants in the wide-screen conditions in Experiments 3 and 4 looked equally at the events they were shown because they could readily generate plausible representations of these events (i.e., two different objects moving back and forth behind a screen wide enough to hide them both), then the infants in the experimental condition in Experiment 5 should look reliably longer than those in the control condition. Such a result would indicate that the experimental infants (a) realized, based on the spatiotemporal information they were given, that only one object was present in the apparatus; (b) detected the featural differences between the ball and box; (c) understood that the one could not transform into the other during their passage behind the screen; and hence (d) were surprised to see the ball and box alternately emerge from the two sides of the screen.

On the other hand, if the infants in the wide-screen conditions in Experiments 3 and 4 tended to look equally at the events they were shown because they were too overwhelmed by the wide screen to detect the differences between the ball and box, then no difference should be found between the responses of the experimental and control infants in Experiment 5, who were again tested with a wide screen.

Method

Subjects

Subjects were 16 healthy full-term infants, 8 male and 8 female (M = 7 months, 14 days; range = 7 months, 0 day to 7 months, 27 days). Three additional infants were tested but eliminated; they failed to complete four valid test trials, one because of fussiness, one because of drowsiness, and one because of experimenter error. Eight infants were randomly assigned to the experimental condition (M = 7 months, 11 days) and eight to the control condition (M = 7 months, 17 days).

Apparatus

The ball, box, familiarization screen, and test screen used in Experiment 5 were identical to those in the experimental wide-screen condition in Experiments 3 and 4. In the control condition, the shorter screen used in the familiarization trials was 45 cm wide and 14 cm high, made of cardboard, and covered with yellow contact paper; the shorter screen used in the pretest-display and test trials was identical to that in Experiments 1 and 2.

Events

Experimental condition. The familiarization and test events shown in the experimental condition were identical to those in the experimental wide-screen condition in Experiment 4, with the following exceptions. At the start of each trial, the screen lay flat on the apparatus floor so that the infants could see the empty area behind the screen; only the ball was visible to the left of the screen. At the end of the pretrial (when the computer signaled that the infant had looked at the ball for 2 cumulative seconds), the second experimenter rotated the screen upward (1 s) and the third experimenter surreptitiously inserted the box into the apparatus (2 s). From this point on, the trials proceeded exactly as in Experiment 4.

The pretest-display trials were identical to those in the experimental wide-screen condition in Experiment 4 except that the wide screen lay flat against the apparatus floor at the start of each trial and was rotated upward (1 s) by the second experimenter.

Control condition. The familiarization, pretest-display, and test events shown in the control condition were identical to those in the experimental condition, except that the shorter screens were used.

Procedure

The procedure used in Experiment 5 was identical to that in Experiment 4. Interobserver agreement during the test trials averaged 96% per test trial per infant.[7] Preliminary analyses of the infants' mean looking times during the test trials revealed no significant Sex $\times$ Condition

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[7] For 15 of the 16 infants in Experiment 5, the primary observer was asked at the end of the test session whether the infant had seen a test event in which the screen rotated upward at the start the event or a test event in which the screen remained upright throughout the event (as in Experiments 3 and 4). The primary observer guessed correctly for only 6 of the 15 infants, a performance not significantly different from chance (cumulative binomial probability, $p > .05$).

interaction, $F(1, 12) = 1.07$, $p > .05$; the data were therefore collapsed across sex in subsequent analyses.

Results

Familiarization Trials

The infants' looking times during the six familiarization trials were averaged and analyzed by means of a one-way ANOVA with Condition (experimental or control) as a between-subjects factor. The main effect of condition was not significant, $F(1, 14) = 0.21$, indicating that there was no reliable difference between the mean looking times of the infants in the experimental ($M = 29.9$ s, $SD = 14.1$) and the control ($M = 32.7$ s, $SD = 10.0$) conditions.

Pretest-Display Trials

The infants' looking times during the two pretest-display trials were averaged and analyzed in the same manner as the familiarization trials. The main effect of condition was again not significant, $F(1, 14) = 1.50$, $p > .05$, indicating that the infants in the experimental ($M = 21.9$ s, $SD = 6.5$) and the control ($M = 17.7$ s, $SD = 7.1$) conditions did not differ reliably in their mean looking times during the pretest-display trials.

Test Trials

The infants' looking times during the four test trials were averaged and analyzed in the same manner as the familiarization and pretest-display trials. The analysis yielded a significant main effect of condition, $F(1, 14) = 4.88$, $p < .05$, indicating that the infants in the experimental condition ($M = 20.5$ s, $SD = 10.0$) looked reliably longer than those in the control condition ($M = 11.8$ s, $SD = 5.0$).

Discussion

During the familiarization and pretest-display trials, the infants in the experimental and control conditions tended to look equally. During the test trials, however, the infants in the experimental condition looked reliably longer than those in the control condition. These results suggest two conclusions. One is that the experimental infants (a) believed, based on the spatiotemporal information they were given, that only one object, the ball, was present in the apparatus; (b) understood that the ball could not transform itself into the box, and vice versa; and hence (c) were surprised during the test trials to see the ball and box alternately emerge from behind the screen. The other conclusion is that, like the experimental wide-screen infants in Experiments 3 and 4, the control infants (a) concluded, based on the featural differences between the ball and box, that they were distinct objects; (b) assumed that the box hid behind the shorter screen at the start of each test trial; (c) realized that the wide screen was sufficiently large to hide both the ball and box; and hence (d) showed little surprise during the test trials.

The results of Experiment 5 thus not only confirm those of the experimental wide-screen condition in Experiments 3 and 4, but also provide evidence against the hypothesis that the infants in this condition showed little or no surprise because they were overwhelmed by the wide screen and failed to notice the featural differences between the ball and box. The experimental infants in Experiment 5 were tested with a wide screen and still had no difficulty detecting the featural changes between the ball and box.

Taken together, the results of Experiments 3, 4, and 5 suggest that, when shown a different-objects occlusion event, infants ages 7.5 months and older assume that two objects are involved in the event and display little surprise at the event, unless (a) they judge that the screen is too narrow to simultaneously hide the two objects (Experiments 3 and 4) or (b) they are first shown that a single object is present in the apparatus (Experiment 5).

EXPERIMENT 6

The 9.5-month-olds in Experiment 2 gave no evidence that they recognized that two distinct objects were involved in the different-objects occlusion event they were shown. In contrast, the 9.5-month-olds in Experiment 3 and the 7.5-month-olds in Experiment 4 all gave clear evidence that they correctly interpreted the different-objects occlusion events they were shown. One interpretation for these results was the one proposed earlier: the infants failed in Experiment 2 because they were tested with an event-mapping task (i.e., they were required to compare an occlusion and a no-occlusion situation), and they succeeded in Experiments 3 and 4 because they were tested with an event-monitoring task (i.e., they were asked to reason about only an occlusion situation). However, it could be objected that there were other differences between the experiments that could have contributed to the discrepancy in their results.

One particularly salient difference between the experiments had to do with the number of violations the infants could see in each ‘‘impossible’’ trial. The infants in Experiment 2 who were shown the ball–box test event saw a single violation per trial, when the screen was lowered at the end of the trial to reveal only the ball. In contrast, the infants in Experiments 3 and 4 who were shown the experimental narrow-screen test event could see multiple violations per trial—each time the box appeared after the ball had disappeared and vice versa. Because the event was repeated continuously until the trial ended, it was possible for an infant to see as many as 11 violations per trial.

Experiment 6 examined whether 7.5-month-olds would still succeed at our width-comparison task if they were presented with a single violation per trial. In addition, to add some degree of generality to our results, the infants

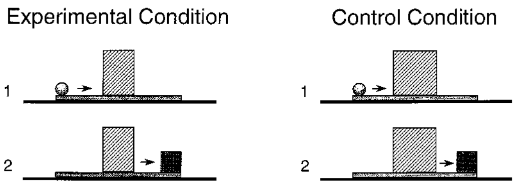

FIG. 7. Schematic drawing of the test events in the experimental and control conditions of Experiment 6.

were tested with two objects of different sizes—the small ball and the large box from Experiments 3 and 4—rather than with two objects of similar sizes, as in the preceding experiments.

The infants were assigned to either an *experimental* or a *control* condition (see Fig. 7). The infants in both conditions saw the small ball move behind a screen; next, the large box emerged from behind the screen and moved to the end of the platform, where it remained stationary until the end of the trial. The only difference between the experimental and the control conditions had to do with the width of the screen, which was either too narrow (experimental condition) or sufficiently wide (control condition) to hide the small ball and large box simultaneously.

We reasoned that positive evidence in Experiment 6 would (a) confirm the results of Experiments 3 and 4, (b) extend these results to slightly different test objects and screens, and (c) establish that infants could succeed at our width-comparison task even when presented, as in Experiments 1 and 2, with a single violation per trial.

Method

Subjects

Subjects were 14 healthy full-term infants, 7 male and 7 female (*M* = 7 months, 19 days; range = 7 months, 8 days to 8 months, 7 days). Three additional infants were tested but eliminated; they failed to complete four valid test trials, two because of fussiness and one because of experimenter error. Seven infants were randomly assigned to the experimental condition (*M* = 7 months, 22 days) and seven to the control condition (*M* = 7 months, 17 days).

Apparatus

The small ball, large box, and familiarization screen used in Experiment 6 were identical to those in Experiments 3 and 4. However, new screens were used in the pretest-display and test trials. The screen used in the experimental condition was 17.75 cm wide and 25.5 cm tall, and the screen used in the control condition was 25 cm wide and 25.5 cm tall. Both screens were made of blue posterboard and covered with clear contact paper. Metal legs attached to the familiarization and test screens slid under the platform and kept the screens upright; the wooden dowel was removed from the apparatus.

Events

Experimental condition. The familiarization event shown in the experimental condition was similar to that in the experimental narrow-screen condition of Experiments 3 and 4 with the following exceptions. First, the ball was replaced with the small ball. Second, a metal clamp was attached to the back of the large box; at the beginning of the familiarization event, the third experimenter held the box centered above the platform behind the screen and lowered the box over the small ball when it moved beneath the box. The box (with the small ball inside it) then moved to the right end of the platform. After it returned behind the screen, the box was lifted off of the small ball, which was then free to move back to its initial position at the left end of the platform. Of course, since the familiarization screen hid the right portion of the platform, the box was never visible.

The pretest displays shown in the experimental condition were identical to those in the experimental narrow-screen condition of Experiment 4 except that the large ball was replaced with the small ball and the narrow screen with the 17.75-cm screen described above.

The test event shown in the experimental condition was identical to the familiarization event except that the 17.75-cm screen was used and the box stopped and remained stationary after it reached the right end of the platform.

Control condition. The familiarization event, pretest displays, and test events shown in the control condition were identical to those in the experimental condition except that the 17.75-cm screen was replaced with the 25-cm screen described above.

Procedure

The procedure in Experiment 6 was similar to that in Experiment 4 except that slightly different criteria were used to end the familiarization and test trials. The minimum length of each familiarization trial was increased from 10 to 12 s (this ensured that the infants had the opportunity to see the ball return to the left edge of the platform before the trial ended), and the minimum length of each test trial was increased from 5 to 7 s (this ensured that the infants had the opportunity to observe the box reach the right edge of the platform before the trial ended).[8] Interobserver agreement averaged 93% per test trial per infant. Preliminary analyses of the infants' mean looking times during the test trials revealed no significant Sex $\times$ Condition interaction, $F(1, 10) = 1.76$, $p > .05$; the data were therefore collapsed across sex in subsequent analyses.

Results

Familiarization Trials

The infants' looking times during the six familiarization trials were averaged and analyzed as in Experiment 5. The main effect of condition was not

[8] Because the minimal length of each test trial in Experiments 3, 4, and 5 was only 5 s, it was possible in principle for a test trial to have ended before the box appeared at the right edge of the screen. If an infant looked continuously for 5 s after the pretrial ended, and then looked away for 0.5 s or more, the trial would have ended while the box was still behind the screen (the box became visible to the right of the screen about 6 s after the pretrial ended). Fortunately, very few infants ever showed this looking pattern, as is suggested by the fact that the mean looking times obtained in these experiments were all considerably greater than 5 s. Only 19 of the 272 test trials (7.0%) in Experiments 3, 4, and 5 had a pattern of a continuous look of less than 6 s, beginning immediately after the pretrial, followed by a look away that ended the trial.

significant, $F(1, 12) = 0.32$, indicating that there was no reliable difference between the mean looking times of the infants in the experimental (M = 32.0 s, SD = 11.5) and the control (M = 28.5 s, SD = 11.9) conditions.

Pretest-Display Trials

The infants' looking times during the two pretest-display trials were averaged and analyzed in the same manner as the familiarization trials. The main effect of condition was again not significant, $F(1, 12) = 2.15$, $p > .05$, indicating that the infants in the experimental (M = 19.0 s, SD = 7.8) and the control (M = 13.2 s, SD = 6.9) conditions did not differ reliably in their mean looking times during the pretest-display trials.

Test Trials

The infants' looking times during the four test trials were averaged and analyzed in the same manner as the familiarization and pretest-display trials. The analysis yielded a significant main effect of condition, $F(1, 12) = 13.58$, $p < .005$, indicating that the infants in the experimental condition (M = 16.5 s, SD = 2.9) looked reliably longer than those in the control condition (M = 11.6 s, SD = 2.0).

Discussion

The infants in the experimental condition looked reliably longer than those in the control condition. These results suggest that the infants (a) concluded, based on the featural differences between the small ball and large box, that they were distinct objects; (b) understood that their combined width relative to that of the screen determined whether they could simultaneously hide behind the screen; (c) judged that the small ball and large box could both hide behind the wide screen used in the control condition but not the narrow screen used in the experimental condition; and hence (d) were surprised in the experimental condition when this judgment was violated.

The results of Experiment 6 thus confirm those of Experiments 3 and 4. In addition, the present results extend these results by demonstrating that infants succeed at our width-comparison task even when shown a single violation per trial, as in Experiments 1 and 2, rather then multiple violations per trial, as in Experiments 3 and 4. As such, the present results provide further support for the conclusion that the infants in Experiment 2 failed because they were given an event-mapping task and that the infants in Experiments 3 and 4 succeeded because they were given an event-monitoring task.

EXPERIMENT 7

The 9.5-month-olds in Experiment 2 were tested with an event-mapping task—they saw first an occlusion and then a no-occlusion situation—and performed poorly. In contrast, the 9.5-month-olds in Experiment 3 and 7.5-month-olds in Experiments 4 and 6 were tested with an event-monitoring task—they saw only an occlusion situation—and performed successfully. These findings, together with those of Xu and Carey (1996), give rise to a number of questions: What is the source of infants' difficulty with event-mapping tasks? Why do infants succeed at event-mapping tasks involving same-object occlusion events before they do so at event-mapping tasks involving different-objects occlusion events (see introduction)? And could a simpler event-mapping task be designed that would enable infants to succeed even with different-objects occlusion events?

Experiments 7 and 8 focused on the last of these questions. Our approach was based on the following assumptions. First, we took it as a given that event-mapping tasks require infants to retrieve a representation of the occlusion situation, compare this representation to the no-occlusion situation before them, and judge whether the two are consistent. Second, we assumed that infants' main difficulty with event-mapping tasks is in retrieving a clear and precise representation of the occlusion situation. Third, we speculated that at least two factors contribute to infants' difficulty in retrieving a representation of the occlusion situation: one is the number of objects involved (which would explain why same-object occlusion events are easier for infants than are different-objects events) and the other is the complexity of the objects' trajectories—including, in particular, the number of reversals the objects perform in or out of view. We reflected that if infants were unable to isolate an individual event cycle or half-cycle within a repeating occlusion sequence, and attempted to retrieve a large portion of the sequence, it would not be surprising if they faltered when processing this large and unwieldy representation.

These assumptions led to the prediction that infants might succeed at an event-mapping task involving a different-objects occlusion event if the event were pared down so that the objects underwent very brief trajectories. Such a modification, we felt, might have the effect of reducing the amount of information the infants could include in their representation of the occlusion situation; reducing this burden might in turn make it easier for the infants to retrieve the representation and compare it to the no-occlusion situation.

The subjects in Experiment 7 were 9.5-month-old infants. They were assigned to a box–ball or a ball–ball condition (see Fig. 8). The infants in the *box–ball* condition saw an event involving the large ball, large box, and wide screen used in Experiments 1 to 5. The event was composed of an initial phase and a final phase. During the initial phase, the infants saw the box emerge to the left of the screen, move to the left end of the platform, and then return behind the screen. Next, the ball emerged to the right of the screen, moved to the right end of the platform, and again returned behind the screen. The screen was then lowered to the apparatus floor, marking the end of the initial phase. During the final phase, the infants saw the ball alone at the center of the platform. The infants in the *ball–ball* condition saw the same test event, except that the ball emerged on both sides of the screen.

The infants in Experiment 7 were thus presented with fewer reversals than

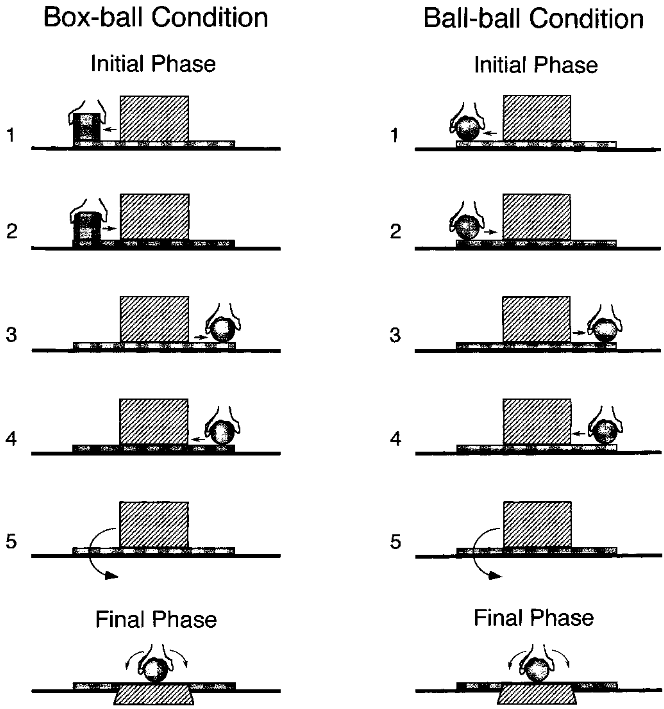

FIG. 8. Schematic drawing of the test events in the box–ball and ball–ball conditions of Experiment 7.

the infants in Experiments 1 and 2: whereas in these experiments the ball and box each reversed direction several times in and out of view, in Experiment 7 each object reversed direction only once, in full view. A further difference between these experiments had to do with which object was seen first and which second in the different-objects occlusion event: in Experiments 1 and 2, the ball was seen first, whereas in Experiment 7, the box appeared first. This modification was introduced to ensure that, in Experiment 7 as in Experiments 1 and 2, the *ball* was the last object seen by the infants before the screen was lowered (this feature of the design required the infants to detect and remember that an object other than the ball had been involved in the event).

In addition to the modifications noted above, there were also a few procedural differences between Experiment 7 and the preceding experiments. First, in order to present the infants with as few object trajectories as possible, the infants were given no familiarization trials; they received only two pretest-display trials followed by one test trial. Second, because there is evidence that infants (a) have difficulty reasoning about occlusion events that involve self-propelled objects if they are not first familiarized with the objects (see Baillargeon, 1995), but (b) can reason about occlusion events involving inert objects moved by a visible hand even when given few or no familiarization trials (e.g., Baillargeon & Graber, 1988; Baillargeon, DeVos, & Graber, 1989; Baillargeon et al., 1990), a visible hand moved the objects along the platform.

Our reasoning was as follows. If the infants were able to (a) retrieve a representation of the initial phase of the event they were shown, (b) map this representation onto the display presented in the final phase of the event, and (c) judge whether the two were consistent, then the infants in the box–ball condition should find the display surprising, but the infants in the ball–ball condition should not. The infants in the box–ball condition should therefore look reliably longer than those in the ball–ball condition.

Method

Subjects

Subjects were 14 healthy full-term infants, 7 male and 7 female (M = 9 months, 16 days; range = 9 months, 7 days to 9 months, 27 days). Three additional infants were tested but eliminated, two because of experimenter error and one because the primary observer had difficulty following the direction of the infant's gaze. Eight infants were randomly assigned to the box–ball condition (M = 9 months, 14 days) and 6 to the ball–ball condition (M = 9 months, 19 days).

Apparatus

The apparatus used in Experiment 7 was similar to that in Experiments 1 and 2 with one exception: a larger slit was created in the back wall to enable an experimenter's hand to reach into the apparatus and move the ball and box. The slit was 6.5 cm high, 52.5 cm long, and was located 10 cm above the apparatus floor. A strip of white fringe 16 cm high and 62 cm long helped conceal the slit.

The box, ball (minus its stick), and screen used in Experiment 7 were identical to those in Experiments 1 and 2. A second, identical ball was also used.

Events

Box–ball condition. Three experimenters worked together to produce the pretest displays and test events. The first wore a black glove and manipulated the objects, the second operated the screen, and the third wore cream-colored gloves and surreptitiously removed the box or identical ball from the apparatus before the screen was lowered.

In the first pretest display, the first experimenter's right hand held the box to the left of the screen and tilted it gently to the left and to the right (once to each side per second) until the end of the trial. In the second display, the hand held the ball to the right of the screen and tilted it gently until the trial ended. The hand held each object from the top.

At the start of the test event, the screen stood upright at the center of the platform. The box and the ball were hidden behind the left and right sides of the screen, respectively. During the *initial phase* of the event, the hand moved the box to the left edge of the platform (2 s), paused (1 s), and then returned the box behind the screen (2 s). Next, the hand moved the ball to the right edge of the platform (2 s), paused (1 s), and then moved the ball back behind the screen (2 s). As in all of the present experiments, when in view the ball and box moved at a rate of about 12 cm/s and remained in full contact with the platform. While the ball was in motion, the third experimenter surreptitiously removed the box from the apparatus through a hidden opening in the back wall. After the ball was returned behind the screen, the second experimenter lowered the screen to the apparatus floor (1 s), marking the end of the initial phase. During the *final phase,* the hand tilted the ball gently at the center of the platform until the trial ended.

Ball–ball condition. The pretest displays and test event shown in the ball–ball condition were similar to those in the box–ball condition except that the second, identical ball was substituted for the box.

Procedure

The procedure used in Experiment 7 was similar to that in Experiments 3 and 4 with a few exceptions. First, the infants were given no familiarization trials; they received only two pretest-display trials and one test trial. Second, looking time during the initial and final phase of the test trial was monitored separately. The final phase of the test trial ended when the infant either (a) looked away for 0.5 consecutive seconds after having looked for at least 4 cumulative seconds or (b) looked for 30 cumulative seconds without looking away for 0.5 consecutive seconds. Interobserver agreement during the final phase of the test trial averaged 94% per infant. Preliminary analyses of the infants' looking times during the final phase of the test trial revealed no significant Sex × Condition interaction, $F(1, 10) = 0.00$; the data were therefore collapsed across sex in subsequent analyses.

Results

Pretest-Display Trials

The infants' looking times during the two pretest-display trials were averaged and analyzed by means of a one-way ANOVA with Condition (box–ball or ball–box) as a between-subjects factor. The main effect of condition was not significant, $F(1, 12) = 0.32$, indicating that the infants in the box–ball ($M = 24.2$ s, $SD = 7.2$) and ball–ball ($M = 22.0$ s, $SD = 7.4$) conditions did not differ reliably in their mean looking times during the pretest-display trials.

Test Trials

The infants' looking times during the final phase of the test trial were analyzed in the same manner as the pretest-display trials. The main effect of condition was again not significant, $F(1, 12) = 0.20$, indicating that the infants in the box–ball condition ($M = 12.6$ s, $SD = 6.3$) did not look reliably longer than those in the ball–ball condition ($M = 14.4$, $SD = 8.5$).

Discussion

The infants in the box–ball and ball–ball conditions in Experiment 7 tended to look equally when the screen was removed to reveal only the ball. Thus, even when presented with a brief different-objects occlusion event in which each object reversed direction only once, the infants in the box–ball condition still failed to detect the discrepancy between the initial and final phases of the event. This negative finding was consistent with the results of Experiment 2 and of Xu and Carey (1996), and, when contrasted with the positive results obtained in Experiments 3, 4, and 6, again underscored infants' marked and persistent difficulty with event-mapping tasks.

In Experiment 8, we decided to make our test events even shorter and simpler than in Experiment 7: the objects no longer reversed direction, but simply moved along the platform from left to right (see Fig. 9). During the initial phase of the event shown to the infants in the *box–ball* condition, the box moved from the left end of the platform behind the screen; after a brief interval, the ball emerged to the right of the screen and moved to the right end of the platform; next, the screen rotated downward, marking the end of the initial phase. During the final phase, the infants saw an empty area behind the screen; only the ball was visible, to the right of the screen. The ball was held by the hand and was tilted gently left and right until the trial ended. The infants in the *ball–ball* condition saw the same event except that the ball appeared on both sides of the screen.

We reasoned that if the infants in Experiment 8 succeeded in (a) retrieving a representation of the initial phase of the event they were shown; (b) mapping this representation onto the display presented in the final phase of the event; and (c) judging whether the two were consistent, then the infants in the box–ball condition should look reliably longer during the final phase than those in the ball–ball condition.

EXPERIMENT 8

Method

Subjects

Subjects were 14 healthy full-term infants, 7 male and 7 female (M = 9 months, 0 day; range = 7 months, 28 days to 9 months, 24 days). Two additional infants were eliminated

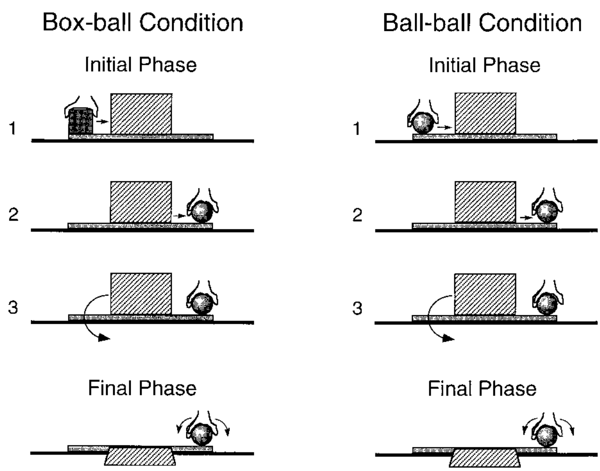

FIG. 9. Schematic drawing of the test events in the box–ball and ball–ball conditions of Experiment 8.

from the experiment, one because of observer error and one because of fussiness. Seven infants were randomly assigned to the box–ball condition (M = 8 months, 26 days) and seven to the ball–ball condition (M = 9 months, 5 days).

Apparatus

The apparatus used in Experiment 8 was identical to that in Experiment 7.

Events

Box–ball condition. The pretest displays shown in the box–ball condition were identical to those in the box–ball condition of Experiment 7.

At the start of the test event, the screen stood upright at the center of the platform. The box stood with its center 6 cm from the left end of the platform, and the first experimenter's right hand tilted the box gently to the left and to the right, once to each side per second. The ball was hidden behind the right edge of the screen. After the computer signaled that the infant had looked at the box for 2 cumulative seconds, the *initial phase* of the test event began. The hand moved the box behind the screen (2 s); the third experimenter then surreptitiously removed the box from the apparatus through a hidden opening in the back wall. Next, the hand moved the ball from behind the screen to the right end of the platform (2 s). The hand then began tilting the ball, as before (2 s). Finally, the second experimenter lowered the screen to the apparatus floor (1 s), marking the end of the initial phase. During the *final phase,* the infants saw the empty area behind the screen and the ball, to the right of the screen, being gently tilted by the hand.

Ball–ball condition. The pretest displays and test event shown in the ball–ball condition were similar to those in the box–ball condition, except that a second, identical ball was substituted for the box.

Procedure

The procedure used in Experiment 8 was identical to that in Experiment 7. Interobserver agreement during the final phase of the test trial averaged 96% per infant. Preliminary analyses of the infants' looking times during the final phase of the test trial did not yield a significant Sex × Condition interaction, $F(1, 10) = 0.19$; the data were therefore collapsed across sex in subsequent analyses.

Results

Pretest-Display Trials

The infants' looking times during the two pretest-display trials were averaged and analyzed as in Experiment 7. The main effect of condition was not significant, (F1, 12) = 1.81, $p > .05$, indicating that the infants in the box–ball (M = 24.4 s, SD = 5.2) and ball–ball conditions (M = 19.9 s, SD = 7.3) did not differ reliably in their mean looking times during the pretest-display trials.

Test Trials

The infants' looking times during the final phase of the test trial were analyzed in the same manner as the pretest-display trials. The main effect of condition was significant, $F(1, 12) = 6.82$, $p < .025$, indicating that the infants in the box–ball condition (M = 19.3 s, SD = 7.0) looked reliably longer than those in the ball–ball condition (M = 11.4 s, SD = 4.0).

Further results. In Experiment 7, the infants in the box–ball and ball–ball conditions tended to look equally when the screen was lowered to reveal the ball; in Experiment 8, in contrast, the infants in the box–ball condition looked reliably longer than did those in the ball–ball condition. Our interpretation for these discrepant results was that they reflected the different trajectories shown in the two experiments: recall that in Experiment 7 the box and ball each reversed direction once, to the side of the screen, whereas in Experiment 8 neither object reversed direction. Presumably, the simpler and shorter trajectories used in Experiment 8 made it easier for the infants to (a) retrieve a representation of the initial phase of the event, (b) compare this representation to the display shown in the final phase of the event; and (c) judge whether the two were consistent. However, there were additional differences between Experiments 7 and 8 that could have contributed to the discrepancy in their results. For example, at the start of the test trial in Experiment 8, the box or ball was visible at the left end of the platform; in Experiment 7, in contrast, the box and ball were both hidden behind the screen. Could such a difference have contributed to the results? We think it unlikely, because the infants in Experiment 2 also saw the ball resting at the left end of the platform at the start of each test trial, and they still produced negative results.

Another difference between Experiments 7 and 8 had to do with the ball's location at the time the screen was lowered. In Experiment 8, the ball was moved to the right end of the platform and then the screen was lowered; in Experiment 7, however, the screen was lowered after the ball had returned behind the screen. The same was true in Experiment 2: the screen was lowered after the ball had moved back behind the screen. Thus, it could be argued that the reason why the infants in Experiment 8 were successful, and those in Experiments 2 and 7 were not, had to do with this difference in the events. Perhaps having the ball visible helped the infants in the box–ball condition in Experiment 8 focus on the issue of what other object was left behind the screen; having the ball visible also meant that the infants had to keep track of just one, as opposed to two, hidden objects.

To examine this alternative interpretation of the results of Experiment 8, seven 9-month-old infants (3 males and 4 females, $M = 9$ months, 2 days; range = 8 months, 13 days to 9 months, 21 days) were tested in a condition similar to the box–ball condition in Experiment 8 with one exception (see Fig. 10): the box was hidden behind the screen at the start of the test event, and the hand first moved the box to the left end of the platform (2 s). From this point on, the event proceeded exactly as in Experiment 8: the box returned behind the screen, the ball moved to the right end of the platform, and the screen rotated downward to the apparatus floor. This test event thus represented an amalgam of the box–ball events in Experiments 7 and 8: the event began as in Experiment 7, but then proceeded as in Experiment 8.

Our reasoning was as follows. If the infants in the box–ball condition in Experiment 8 succeeded because the ball was visible when the screen was

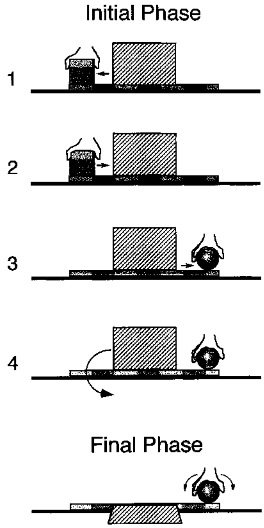

FIG. 10. Schematic drawing of the test event in the modified box–ball condition of Experiment 8.

lowered, then the infants in this modified box–ball condition should also be successful because the ball was again visible. On the other hand, if the infants in Experiment 8 succeeded because they were presented with extremely simple object trajectories, ones that involved no reversal, then it was conceivable that adding even a single reversal at the start of the box–ball event might produce negative results.

The looking times of the infants in the modified box–ball condition during the two pretest displays were averaged ($M = 27.5$ s, $SD = 3.4$) and compared to those of the infants in the box–ball ($M = 24.4$ s, $SD = 5.2$) and ball–ball ($M = 19.9$ s, $SD = 7.3$) conditions in Experiment 8 by means of a one-way ANOVA with Condition (modified box–ball, box–ball, or ball–ball) as a between-subjects factor. The main effect of condition was not significant, $F(2, 18) = 3.32$, $p > .05$, indicating that the infants in the three conditions did not differ reliably in their mean looking times during the pretest-display trials. The looking times of the infants in the modified box–ball condition during the final phase of the test trial were analyzed in the same manner at the pretest-display trials. The analysis yielded a significant main effect of condition, $F(2, 18) = 4.06$, $p < .05$. Planned contrasts revealed that the infants in the box–ball condition ($M = 19.3$ s, $SD = 7.0$) looked reliably longer than those in the modified box–ball ($M = 12.9$ s, $SD = 5.2$) and ball–ball ($M = 11.4$ s, $SD = 4.0$) conditions, $F(1, 18) = 7.84$, $p < .025$, who did not differ among themselves, $F(1, 18) = 0.26$. These results make clear just how fragile is infants' competence at event-mapping tasks involving different-objects occlusion events: adding a *single* reversal at the start of the box's trajectory was sufficient to reduce the infants to the same level of performance as in Experiments 2 and 7. At the same time, the present results help us better understand the negative findings obtained in these experiments and in those of Xu and Carey (1996): clearly, if infants are unable to cope with a single object reversal, they could deal no better with the multiple reversals shown in these experiments.

Final results. We saw earlier that the infants in the box–ball condition in Experiment 8 looked reliably longer than those in the ball–ball condition. We take this result to mean that the infants (a) succeeded in retrieving a representation of the initial phase of the event they were shown, (b) mapped this representation onto the display presented in the final phase of the event, and (c) correctly judged whether there existed a discrepancy between them.

It could be objected that there was another, far less impressive explanation for the results of Experiment 8: perhaps the infants in the box–ball condition were intrigued by the sight of the box in the initial phase of the event, and this had the effect of enhancing their responses during the final phase of the event. This explanation seemed highly unlikely in light of the negative results obtained in the ball–box condition in Experiment 2, in the box–ball condition in Experiment 7, and in the modified box–ball condition just described: all of these infants saw the box during the initial phase of the test event they were shown, but they still failed to show heightened responses during the final phase of the event. Nevertheless, to provide additional evidence against this interpretation of Experiment 8, 14 9-month-olds (8 males and 6 females, $M = 9$ months, 0 day, range = 8 months, 1 day to 9 months, 26 days) were tested in a control experiment identical to Experiment 8 with one exception (see Fig. 11): when the screen was lowered, a second, shorter screen (taller than the box) was revealed that hid the central portion of the platform. The shorter screen was the same as in Experiments 1, 2, and 5.

We reasoned that if the infants in the box–ball condition in Experiment 8 looked reliably longer than those in the ball–ball condition simply because seeing the box and its trajectory heightened their responses during the final phase of the event, then the infants in the control box–ball condition should also look longer than those in the control ball–ball condition. On the other hand, if the infants in the box–ball condition in Experiment 8 looked longer because they were puzzled *not* to see the box when the screen was lowered, then the infants in the control box–ball condition, who could assume that the box lay hidden behind the shorter screen, should respond in the same manner as the infants in the control ball–ball condition.

The infants' looking times during the final phase of the test trial were analyzed by means of a one-way ANOVA with Condition (control box–ball or control ball–ball) as a between-subjects factor. The main effect of condition was not significant, $F(1, 12) = 0.00$, indicating that there was no reliable

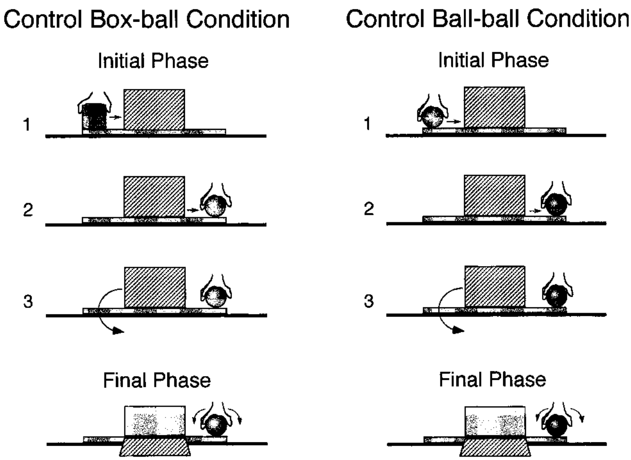

FIG. 11. Schematic drawing of the test events in the control box–ball and ball–ball conditions of Experiment 8.

difference between the looking times of the infants in the control box–ball (M = 13.2 s, SD = 4.4) and the control ball–ball (M = 13.1 s, SD = 6.8) conditions.

Discussion

The infants in the box–ball condition in Experiment 8 looked reliably longer than those in the ball–ball condition. These results suggest that the infants were able to (a) retrieve a representation of the initial phase of the event, (b) map this representation onto the display shown in the final phase of the event, and (c) correctly judge whether the two were consistent. As such the present results provide the first experimental evidence that infants less than 12 months of age can succeed at an event-mapping task involving different-objects occlusion events.

As was mentioned earlier, we believe that the infants in Experiment 8 performed better than those in Experiments 2 and 7 because they were presented with extremely simple and short object trajectories: recall that each object simply moved from left to right—the box moved behind the screen's left edge and then the ball emerged from behind the screen's right edge—before the screen was lowered. In Experiments 2 and 7, in contrast, each object underwent one or more reversals before the screen was lowered. Infants also failed in the modified box–ball condition described above in which the box alone underwent a reversal at the start of the event; this single reversal was sufficient to hinder the infants' performance, resulting in negative results.[9]

[9] It should be noted that in Experiments 1, 2, 7, and 8, the number of reversals that the objects performed was inextricably linked to the number of times that the objects emerged

Why does the number of reversals shown in the initial phase of the event have such a dramatic impact on infants' performance in the present task? This finding is especially striking when one considers the results of Experiments 3 and 4. The infants in these experiments also had to use featural information to distinguish the ball and box, and they were shown multiple object reversals within and across the familiarization and test events; yet they readily succeeded at the task they were given. Why were the infants in Experiments 2 and 7 overwhelmed by the reversals they were shown, but not the infants in Experiments 3 and 4? We return to this question in the Conclusion.

CONCLUSION

The present research examined infants' ability to use featural information to individuate the objects in different-objects occlusion events. To assess infants' interpretation of the events, two types of task were used. One was an event-monitoring task: infants watched a different-objects occlusion event and judged whether the screen was sufficiently wide to hide the two objects simultaneously. The other type of task was an event-mapping task: infants first watched a different-objects occlusion event (and, presumably, judged whether the two objects could simultaneously hide behind the screen); next, the screen was removed, creating a no-occlusion situation, and infants judged whether the number of objects displayed corresponded to that in the occlusion event.

The results obtained with the two types of task were as follows. First, infants readily succeeded at the event-monitoring tasks but not the event-mapping tasks. Second, infants succeeded at the event-mapping tasks only when the events were pared down so that the object on each side of the screen presented a single, left-right trajectory; if one or both of the objects underwent one or more reversals, the infants' performance deteriorated.

The present results, together with those of Xu and Carey (1996), raise three important questions. First, why are event-monitoring and event-mapping tasks so different for infants? Second, why do infants perform better in event-mapping tasks that involve (a) same- as opposed to different-objects occlusion events or (b) different-objects occlusion events that are pared down to the extent that the objects undergo no reversal? And finally, why do infants readily succeed at event-mapping tasks in which they can use spatiotemporal rather than featural information to individuate the objects? Each of these questions is considered in turn.

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from behind the screen. Hence, it could be argued that number of emergences, rather than number of reversals, led to the mapping difficulties observed. Further research is needed to clarify this issue; in the present context, we refer only to number of reversals.

Event Monitoring and Event Mapping

The crucial difference between the event-mapping and event-monitoring tasks used here, we have argued, is that in the former, infants are faced first with an occlusion and then with a no-occlusion situation, whereas in the latter the infants are presented only with an occlusion situation. But why should the screen's removal make such a difference for infants?

It might be suggested that infants represent occluded and unoccluded objects very differently and that the screen's removal creates difficulties for infants because it forces them to change the representational status of the objects involved in the events. Such an explanation is very unlikely. Recall that in the event-monitoring task used in Experiments 3 and 4, the ball and box moved continually back and forth behind the screen, resulting in multiple occlusions and unocclusions; nevertheless, the infants succeeded at the task, indicating that even repeated alternations between an occluded and an unoccluded status did not interfere with the infants' ability to reason about the ball and box.

A more likely explanation for why the screen's removal makes such a difference to infants, we believe, is that it radically alters their *categorization* of the physical situation before them. This category change would not only force infants to set up a new representation, but—in the interest of making sense of the world as it unfolds, rather than dealing with only independent snapshots of the world—would also call for some *linkage* between the two situations. It would be in their attempt to retrieve their representation of the initial situation and map it onto the new situation—to determine whether the two situations form a pattern consistent with their physical knowledge—that infants would run into difficulty.

According to this explanation, when the infants in the present event-mapping tasks saw the ball and box move back and forth behind the screen, they categorized the situation before them as one of occlusion; everything that happened within the situation—the ball and box becoming repeatedly occluded and unoccluded—was processed within this initial representation. When the screen was later removed, the infants assigned the situation to a novel category which, for lack of a better term, we have referred to as one of no-occlusion. This new representation in turn compelled the infants to seek a linkage between their old and new representations.

The explanation just proposed assumes that infants categorize the physical situations that they observe into broad categories. Why would infants engage in such a process? Our model of infants' acquisition of physical knowledge (e.g., Baillargeon, 1994, 1995, 1998; Baillargeon et al., 1995) suggests an answer to this question. According to this model, infants are born with a specialized learning mechanism that is responsible for at least two processes. The first is the *formation of physical categories* that correspond to distinct ways in which objects behave and interact. Examples of infants' physical categories include occlusion, collision, support, arrested-motion, and containment situations. The second process is the *identification, for each physical category, of an initial concept and variables.* According to the model, when learning about a physical category, infants first form a preliminary, all-or-none concept that captures only the essence of the category. With further experience, this initial concept is progressively elaborated. Infants slowly identify variables that are relevant to the category and incorporate this additional knowledge into their reasoning, resulting in increasingly accurate predictions over time.

Our model of physical reasoning thus provides an explanation for why infants assign the different physical situations that they observe to different categories: this categorization process is a crucial part of infants' approach to learning about the physical world. Infants assign physical situations to broad categories and interpret what they observe, predict outcomes, gather information about potential variables, and so on, all in terms of the selected categories.

The preceding arguments can be summarized as follows. First, infants are born with a bias to form distinct physical categories and to reason and learn in terms of these separate categories. Second, although this bias must in general considerably facilitate infants' acquisition of physical knowledge—breaking down the task of learning into smaller, more manageable components is a time-honored solution to the difficulties of knowledge acquisition—it also carries a few limitations. Infants' difficulties with event mapping, we believe, constitute one such limitation. When infants are presented with a physical situation from one category and then with a situation from a different category, they set up distinct representations for the two situations. Infants attempt to link up their representations of the old and new situations, to keep track of the world as it unfolds, but, as we have seen, they are often unsuccessful in this attempt.

Recent research has brought to light another limitation that results from infants' bias to form distinct physical categories and to reason and learn in terms of these separate categories (Hespos & Baillargeon, 1998). Specifically, infants must sometimes learn similar variable knowledge again and again for different physical situations. This research compared 5-month-olds' reasoning about height in containment and occlusion events. The infants in the *containment* condition saw a possible and an impossible test event. At the start of each event, a hand grasped a knob affixed to the top of a tall cylindrical object; the hand lifted the object above a container and then lowered it until only the knob was visible above the container's rim. The height of the container differed in the two test events: one container was as tall as the object, minus the knob (possible event), whereas the other container was only half as tall as the object (impossible event), so that it should have been impossible for the object to be fully lowered into the container. Prior to the test trials, the infants received familiarization trials in which the containers were rotated forward so that the infants could inspect them. The infants in the *occlusion* condition saw identical events, except that the bottom and back half of each container were removed to create a rounded occluder. The infants in the occlusion condition looked reliably longer at the impossible than at the possible test event, whereas the infants in the containment condition tended to look equally low at the two events. These and control results suggested that 5-month-old infants (a) realize that the height of an object relative to that of an occluder determines whether the object will be fully or only partly hidden when lowered behind the occluder, but (b) have *not* yet learned that the height of an object relative to that of a container predicts whether the object will be fully or only partly hidden when lowered into the container. This interpretation was supported by an additional experiment in which the tall object was lowered *behind* rather than into the containers; the infants looked reliably longer at the impossible event, suggesting that they categorized the situation as one of occlusion and hence were able to bring to bear their knowledge about height. Together, these results indicate that infants learn about height first in occlusion and again later in containment events. More generally, these results suggest that infants regard occlusion and containment as distinct physical categories and reason and learn separately about the two categories.

The preceding discussion leads to the prediction that infants should experience event-mapping difficulties, not only when shown occlusion and no-occlusion situations, as in the present research, but also when shown other pairs of physical situations. To test this prediction, Hespos and Baillargeon have undertaken experiments involving successive occlusion and containment situations. These experiments will provide an especially strong test of the present approach because both involve (from an adult perspective) objects becoming occluded. Evidence that infants experience difficulties comparable to those identified in Xu and Carey (1996) and in the present research will lend strong support to the notion that event mapping is a general consequence of infants' bias to view the world in terms of distinct event categories.

Mappings Based on Featural Information

The present results and those of Xu and Carey (1996) suggest that, when given an event-mapping task and forced to use featural information to individuate the objects in the occlusion situation, infants ages 10 months and younger (a) perform well with a *different-objects* occlusion event only if the event is pared down so that each object undergoes no reversal and (b) perform well with a *same-object* occlusion event even if the object undergoes multiple reversals in and out of view. How can we explain these findings? The most likely hypothesis, we believe, is that they reflect the process infants engage in when they attempt to retrieve a representation of the occlusion event to compare it to the no-occlusion event. Two versions of this hypothesis are described below.

A first version is that infants' success at retrieving a valid representation of the occlusion event depends on two factors: the number of objects involved in the event and the number of reversals performed by each object. The underlying cause for this interaction might be a binding problem (e.g., Cohen & Eichenbaum, 1993). Infants might find it relatively easy to bind in memory a *single* object to its trajectory, but experience considerable difficulty binding *two* objects to their respective trajectories; in the latter case, infants must not only retrieve two separate objects and two separate trajectories, but they must also keep straight which object was bound to which trajectory. For this reason, only very simple trajectories involving no reversal would enable infants to overcome their binding limitations and achieve some measure of success.

According to this first hypothesis, then, infants who were tested with a same-object occlusion event would have no difficulty (a) retrieving a coherent representation of the event (because the binding problem is simple with only one object) and (b) comparing this representation to the no-occlusion event. In contrast, infants tested with a different-objects occlusion event, and especially one involving multiple reversals, (a) would be unable to retrieve a coherent representation of the event in which each object was correctly bound to its trajectory and hence (b) would have no representation, or too poor a representation, to compare to the no-occlusion event.[10]

A second hypothesis, which is subtly different from the first, is that it is ambiguity, rather than binding complexity, that limits infants' success at retrieving representations of occlusion events. When faced with a same-object occlusion event, infants very likely achieve a clear, unambiguous interpretation of the event: they assume that they are watching a single object moving back and forth behind a screen, and they have a fair idea at every point in time of where the object is and what direction it is pursuing. As a result, infants subsequently have no difficulty retrieving a coherent representation of the occlusion event and comparing it to the no-occlusion event. It may even be that, instead of retrieving a representation of the entire event that they observed (the object's multiple reversals), infants use a sort of *summary* representation (e.g., a single event cycle or half-cycle) that simplifies the comparison process even further. In contrast, when presented with a different-objects occlusion event, infants most likely form a representation that contains some ambiguity. Infants cannot know, for example, where the first object stops and the second object starts behind the screen or whether the

[10] One may wonder why the infants in Experiments 3 and 4 who received event-monitoring tasks were not hampered by binding difficulties (recall that these infants also saw different-objects occlusion events involving multiple reversals). Since these infants did not need to compare the occlusion situation before them to any other situation, they never had to retrieve a representation of the occlusion situation and hence never had to solve the problem of binding each object to its trajectory in memory.

first object contacts the second one and causes its motion. Furthermore, it may be difficult for infants to isolate a single cycle or half-cycle within a repeating different-objects occlusion event—to identify the main components of the event and recognize that they are articulated into a single, repeating structure. Because of these various ambiguities, infants are not able to retrieve a summary representation of the event. Therefore, they adopt a different strategy: they attempt to recall the successive segments of the event and to link them together into a complete, *literal* representation of the event. Because of memory and processing constraints, however, infants succeed only with the briefest of events.

According to this second hypothesis, then, infants perform differently with same-object and different-objects occlusion events because they adopt different strategies. With a same-object event, infants (a) retrieve a summary representation of the event and (b) compare it to the no-occlusion event. With a different-objects event, however, infants cannot retrieve a summary representation; instead, they attempt to (a) retrieve the entire event that they observed and (b) compare it to the no-occlusion event. In these efforts, they succeed with shorter but not longer occlusion events.

The ambiguity hypothesis proposed here echoes a large body of evidence on children's analogical reasoning (e.g., Brown, 1989, 1990; Crisafi & Brown, 1986; Brown, Kane, & Echols, 1986; Gentner & Toupin, 1986; Goswami & Brown, 1990), which has shown that the more explicit or well understood is the structure of an event sequence, the more likely children are to remember the structure and map it onto a new problem context (see Mani & Johnson-Laird, 1982, for related results on adults' recall of ambiguous and unambiguous descriptions). Further research will help determine whether this approach, the binding approach discussed earlier, or perhaps some amalgam of the two, best explains the complexities of event mapping.

Mappings Based on Spatiotemporal Information

As was mentioned in the introduction, Xu and Carey (1996) found that 10-month-olds succeed at an event-mapping task involving a different-objects occlusion event if they are able to use spatiotemporal information to individuate the two objects—in other words, if they are shown the two objects *side by side* prior to seeing the event. These results echo additional results, also discussed in the introduction, having to do with infants' responses in event-mapping tasks involving same-object occlusion events: here again, infants seem to perform better if they have available spatiotemporal (e.g., Simon et al., 1995; Woodward et al., 1993; Wynn, 1992) information to interpret the events.

Why does the availability of spatiotemporal information, in addition to featural information, facilitate infants' performance in event-mapping tasks? We argued above that (a) event-mapping tasks are harder because they require infants to link their representation of one event with another event from a different physical category and (b) when no spatiotemporal information is available to individuate the objects in the occlusion event, infants perform best when they are able to use in the comparison process a coherent representation of the occlusion event (e.g., a summary representation for a well-understood event and a literal representation for one that is less well specified). This approach makes clear why spatiotemporal information is so easy for infants to use: it provides them with simple and unambiguous information about the objects involved in the occlusion event. When they compare the occlusion and no-occlusion events, to align their objects and make sure that they correspond, infants have only to retrieve their representation of the spatiotemporal information to succeed; they do not need to focus on the occlusion event itself and on the objects' repeated passages behind the screen.

A common theme that runs through the preceding discussion is that, to the extent that infants must compare two distinct events, anything that facilitates the comparison by providing a simple and unambiguous representation of the objects involved in the first event increases the likelihood of the infants' success. In this context, it is worth mentioning that, according to Xu and Carey (1996), the availability of verbal labels for the objects involved in a different-objects occlusion event facilitates infants' reasoning about the event. Verbal labels would, of course, constitute excellent summary representations for infants to use when comparing objects across events.

Concluding Remarks

The impact of the present research is threefold. First, it presents intriguing and, in some respects, counterintuitive experimental findings. Who could have predicted, for example, that infants would find it easy to judge whether two objects could fit simultaneously behind a screen, but would find it difficult to predict what objects would be revealed when the screen was lowered? And who could have known that infants' difficulty with this task would be tied to the number of reversals performed by the objects on either side of the screen?

Second, our attempts at explaining these and related findings have led us to a conceptual analysis that builds on and extends prior research in the infancy literature. New distinctions have been introduced, such as that between event mapping and monitoring, that provide a useful organizing framework for previous as well as future work.

Finally, and perhaps most importantly, the present research underscores the need for a *theory of representation* that spells out how infants form and use their representations of physical events. In the past, infancy researchers were often concerned primarily with establishing at what age infants begin to demonstrate specific cognitive abilities. However, it is obvious, within the context of the present research, that a statement such as ''by 7.5 months of age, infants can use featural information to individuate objects in occlusion events'' cannot even begin to capture the complexities and subtleties of the reasoning processes examined here. As such, the present findings provide a strong impetus for accounts of infants' reasoning that attempt to spell out the nature and properties of infants' mental representations.

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