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Infants' use of speed information to individuate objects in occlusion events

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Abstract

The present research investigated infants' ability to use speed information to individuate objects in occlusion events. In Experiment 1, 7.5- and 4.5-month-olds were presented with a discontinuous-speed occlusion event; the screen was then lowered and infants saw a single object on the platform. The infants responded as if they (a) concluded that two objects were involved in the event; (b) expected to see two objects when the screen was lowered; and (c) were surprised when this expectation was violated. In Experiment 2, 4-month-olds were tested using the same procedure and negative results were obtained, a finding consistent with those of Spelke, Kestenbaum, Simons, and Wein (1995). Experiment 3 explored whether younger infants might reveal an ability to use speed information if a different, more sensitive, individuation task was used; positive results were obtained. Together, these results suggest that speed of motion is fundamental to the individuation process.

Keywords: Occlusion events; Object individuation; Spatiotemporal information

1. Introduction

As they look about them, infants often see objects move in and out of view behind nearer objects or occluders. One problem that occlusion events create for infants is that of object individuation: infants must determine whether the object that reappears from behind an occluder is the same object that disappeared earlier or a different object. Over the last 15 years, a great deal of research has explored infants' ability to establish what objects—what separate and

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distinct entities—are present in occlusion events (e.g., Aguiar & Baillargeon, 2002; Leslie, Xu, Tremoulet, & Scholl, 1998; Spelke et al., 1995; Tremoulet, Leslie, & Hall, 2001; Wilcox, 1999; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Chapa, 2002; Wilcox & Schweinle, 2002; Xu & Carey, 1996). Most of this research has focused on infants' ability to use featural information to individuate objects (Leslie et al., 1998; Tremoulet et al., 2001; Wilcox, 1999; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Chapa, 2002; Wilcox & Schweinle, 2002; Xu & Carey, 1996). Considerably fewer experiments have investigated infants' ability to draw on spatiotemporal information to individuate objects (Aguiar & Baillargeon, 2002; Spelke et al., 1995; Xu & Carey, 1996). Considering the importance of spatiotemporal information to theoretical accounts of object individuation, the lack of empirical work is somewhat surprising. The present research attempted to fill this void by examining whether infants aged 3.5 months and older could use one kind of spatiotemporal information, speed of motion, to determine whether the objects that disappeared and reappeared from behind an occluder were the same or different objects.

1.1. Infants' sensitivity to spatiotemporal information

From a very early age infants demonstrate sensitivity to the spatiotemporal properties of objects. For example, there is evidence that by 2.5 to 3 months of age infants (a) view objects as permanent entities that continue to exist even when out of view; (b) recognize that two objects cannot occupy the same location at the same time, just as one object cannot be in two different locations at the same time; and (c) expect objects to move on spatiotemporally connected paths (e.g., Aguiar & Baillargeon, 1999, 2002; Baillargeon, 1987, 1991; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987; Baillargeon, Graber, DeVos, & Black, 1990; Hespos & Rochat, 1997; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Spelke et al., 1995; Wilcox, 1999; Wilcox & Baillargeon, 1998a, 1998b; Wilcox, Nadel, & Rosser, 1996; Wynn, 1992). One question that is suggested by this last finding is whether infants interpret spatiotemporal discontinuities as signaling the presence of distinct objects.

Some spatiotemporal discontinuities are obvious violations of physical laws and clearly specify the presence of at least two distinct objects. One example of such a discontinuity is a spatiotemporal gap in an object's path of motion. Spelke and her colleagues (Spelke et al., 1995; see also Spelke & Kestenbaum, 1986) investigated 4-month-olds' interpretation of a discontinuous-path event. For example, in one experiment, infants were habituated to an event in which a cylinder moved back and forth along a horizontal track; two screens stood at the center of the track, separated by a gap. The cylinder disappeared behind one screen and, after a brief interval, emerged from behind the other screen, without appearing in the gap between the screens. Following habituation trials, the two screens were removed and the infants saw a one- and a two-cylinder test event on alternating test trials. The infants looked reliably longer at the one- than at the two-cylinder test event. These and control data (from infants who were shown only the test events) suggested that the infants (a) concluded, after observing that no cylinder appeared in the gap between the screens, that two distinct cylinders were involved in the habituation event; (b) expected to see two cylinders when the screens were removed; and (c) were intrigued when this expectation was violated.

The positive results obtained by Spelke and her colleagues (Spelke & Kestenbaum, 1986; Spelke et al., 1995) have been confirmed and extended in experiments conducted with both younger (3.5-month-olds, Aguiar & Baillargeon, 2002) and older (5.5-month-olds, Wilcox & Schweinle, 2002; 10-month-olds, Xu & Carey, 1996) infants. Together, these results leave little doubt that path discontinuities, which typically violate physical laws (i.e., objects cannot move from one location to another without traversing the space in between), are fundamental to the individuation process.

1.2. Object individuation and discontinuities in speed of motion

There are other spatiotemporal discontinuities, however, that do not specify the presence of multiple objects as clearly as the one discussed above. One example of these is a discontinuity in speed of motion. Consider the following example: an object moves behind one edge of a screen and then immediately reappears at the other edge. Does the discontinuity in speed of motion signal the presence of two objects? The answer to this question is not immediately apparent. While it is true that freely moving objects maintain a constant speed in the absence of forces, it is not true that objects always move at a uniform speed. Indeed, self-moving objects often alter their rate of motion; because the forces behind these alterations are not always obvious, and in fact can be difficult to identify, speed of motion may not be perceived as a reliable source of information for tracking objects as they move in and out of view (Spelke et al., 1995). To further complicate matters, somewhat different rules apply to inert objects. For example, a self-moving object might accelerate without an obvious cause, whereas the movements of an inert are dependent on a visible force (i.e., a hand moves the object). In light of these ambiguities, one might wonder about the development of the ability to use speed of motion as the basis for object individuation. We will first explore how adults respond to discontinuities in speed of motion, and then turn to data collected with infants.

1.2.1. Adult data

Although much attention has been paid to adults' sensitivity to motion-carried information in object perception (e.g., Gibson, 1966; Kaplan, 1969; Vicario & Kiritani, 1999), few experiments have focused on adults' ability to use speed of motion as a basis for individuating objects in occlusion events. In a series of experiments, Burke (1952) systematically examined how adults interpreted an event in which an object was occluded for a period of time that was either consistent, or inconsistent, with its speed of motion. In these experiments, an object moved behind one edge of an occluder; after a predetermined interval an identical object emerged at the other edge. Burke used relatively small objects and varied the object's rate of motion, the width of the occluder, and the time the object was out of view.[1] The results most pertinent to this article can be summarized as follows: (1) when the width of the screen and the occlusion interval were concordant, adults perceived a single object moving at a uniform speed behind the screen; (2) when the width of the screen and the occlusion interval were only slightly discordant, adults perceived a single object that changed its speed of motion, or underwent a "hitch," behind the screen; and (3) when the width of the screen and the occlusion interval were clearly discordant, adults assumed that two objects were involved, one that stopped and another that started behind the screen. The most optimal condition for perceiving two distinct objects was obtained when the second object reappeared immediately to the opposite side of a wide screen. Other researchers have similarly reported that adult observers are more likely to unambiguously refer to two objects when an object's entry at one edge, and exit at the other, occur almost at the same instance (see Michotte, Thines, & Crabbe, 1964/1991). These results indicate that, under the right conditions, adults interpret a speed discontinuity as involving two separate objects that follow non-overlapping trajectories behind the screen.

1.2.2. Infant data

Burke's (1952) (see also Vicario & Kiritani, 1999) results raise the question of whether infants might also demonstrate a sensitivity to discontinuities in speed of motion. There is evidence that infants expect moving objects to follow linear paths at uniform speeds even when occluded, and adjust their visual tracking and reaching behavior accordingly (for a review, see von Hofsten, 1997). There is a difference, however, between having an expectation that objects will move smoothly through space and using a speed discontinuity to infer the presence of two distinct objects. Recently, Spelke and her colleagues (Spelke et al., 1995; see also Spelke & Kestenbaum, 1986) directly tested infants' ability to use speed information to individuate objects in an occlusion event. In one experiment (Spelke et al., 1995), for example, 4-month-olds were habituated to one of three events: constant speed, changed speed, or immediate reappearance. In all three events, infants saw a cylinder move behind the left edge of a screen and, after a predetermined interval, an identical object emerge from behind the right edge of the screen. The cylinder then reversed direction and returned to its original position. The event was repeated until the trial ended. In the *constant-speed* event, the object was occluded for an interval appropriate for its speed of motion; in the *changed-speed* event, the object reappeared too quickly for its speed of motion; finally, in the *immediate-reappearance* event the object emerged immediately at the other edge of the screen.[2] Following habituation, the screen was removed and the infants saw a one- and a two-cylinder test event on alternating test trials. The infants in the three conditions looked about equally at the test events, and their looking times did not differ reliably from those of control infants who saw only the test events. Together, these results suggested that the infants failed to draw a conclusion about the number of objects involved in the constant-speed, changed-speed, and immediate-reappearance habituation events. Unlike adults (Burke, 1952), these infants did not use speed information to individuate objects in occlusion events.

1.3. Present research

The research reviewed above suggests that 4-month-olds do not use discontinuities in speed of motion to signal the presence of numerically distinct objects. The present research asked at what age infants might first demonstrate sensitivity to speed information. Two experiments were conducted with infants 4, 4.5, and 7.5 months of age using a task similar to that of Spelke et al. (1995). Positive results were obtained with the 4.5- and 7.5-month-olds, but not with the 4-month-olds. To explore whether younger infants might succeed if this ability was assessed in a different way, a third experiment was conducted with 3.5-month-olds using an easier task.

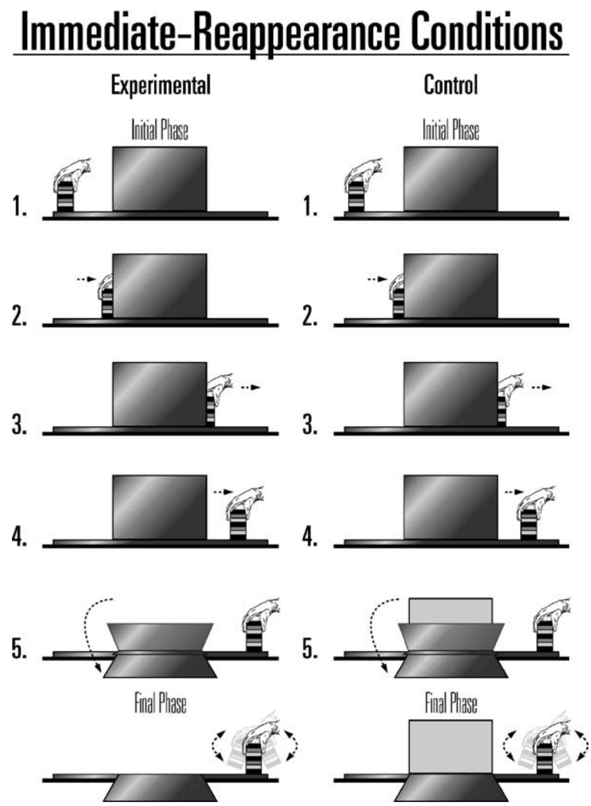

Fig. 1. Schematic drawing of the test events in the immediate-reappearance conditions, experimental and control, of Experiments 1 and 2.

2. Experiment 1

Experiment 1 examined 4.5- and 7.5-month-olds' interpretation of a speed discontinuity using a task similar to that of Spelke et al. (1995), but simplified in a number of respects. The infants were assigned to one of two *immediate-reappearance* conditions (Fig. 1): experimental or control. The infants in the experimental condition saw a test event composed of an initial and a final phase. During the initial phase, the infants saw a column standing to the left of an upright screen. After a pause, the column moved behind the left edge of the screen and then immediately reappeared at the right edge. Finally, the screen was lowered to the apparatus floor. During the final phase of the test event, the infants saw only the column to the right of the screen (the area behind the lowered screen was empty). The infants in the control condition saw an identical test event with one exception: during the final phase a second, shorter screen stood behind the lowered screen, thereby hiding the area behind it. We reasoned that if the experimental infants (a) were led by the speed discontinuity to conclude that two columns were involved in the immediate-reappearance event and therefore (b) expected to see two columns when the screen was lowered, then they should find the final phase display anomalous or surprising. Furthermore, if the control infants (a) concluded that the immediate-reappearance event involved two distinct columns but also (b) realized that the first column could be hidden behind the shorter screen, then they should not find the final phase display anomalous. Because infants' surprise at a display typically manifests itself by prolonged attention to the display (e.g., Bornstein, 1985; Spelke, 1985), we predicted that the infants in the experimental condition would look reliably longer than those in the control condition.

It was possible, however, that the infants in the experimental condition might look longer at the final display for reasons that did not involve object individuation. For example, the infants might note the change in the screen in the initial and final phases of the event (i.e., upright screen vs. no upright screen) and find this change interesting. Alternatively, the infants might simply prefer displays containing a fully visible platform to displays containing a partly occluded platform. In other words, the infants might disregard the columns and their motions altogether, and instead attend to other aspects of the test event. To control for this possibility, additional infants were tested in one of two *normal-reappearance* conditions (Fig. 2): experimental or control. The infants in these conditions saw test events similar to those of the infants in the corresponding immediate-reappearance conditions (experimental or control) with one main difference: the occlusion interval was appropriate for the columns' rate of motion. If the infants in the immediate-reappearance conditions responded differentially during the final phase of

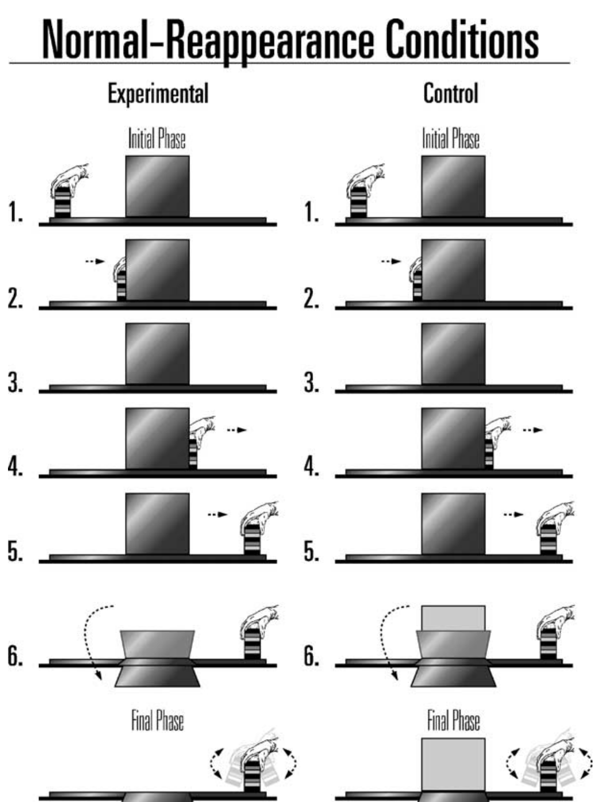

Fig. 2. Schematic drawing of the test events in the normal-reappearance conditions, experimental and control, of Experiments 1 and 2.

the test event because of a preference for one screen display over another, then the infants in the normal-reappearance conditions, who saw similar screen displays, should respond in a like manner. That is, the experimental infants should look longer at the final display than the control infants. In contrast, if the infants in the immediate-reappearance experimental condition looked longer at the final display because they were puzzled *not* to see a second column when the screen was lowered, then the infants in the normal-reappearance experimental condition, who saw an occlusion event consistent with the presence of a single object, should not find the final one-column display surprising.

In designing the immediate- and normal-reappearance events it was not possible to vary whether the column emerged immediately or after an interval appropriate for its rate of motion and hold all other variables constant. We decided to hold constant the length of the initial phase of the event (9 s) and the amount of time the columns were in motion during that time (5 s). We varied the speed of the columns when visible, the width of the screen, and of course, the time of occlusion. (For a detailed discussion of why we chose to manipulate these variables, see the description of the normal-reappearance experimental event in the Section 2.1.)

2.1. Method

2.1.1. Participants

Participants were 28 4.5-month-olds, 14 male and 14 female ($M = 4$ months, 23 days; range = 4 months, 13 days to 5 months, 6 days) and 28 7.5-month-olds, 14 male and 14 female ($M = 7$ months, 15 days; range = 7 months, 1 day to 8 months, 4 days). In this and all subsequent experiments, infants were healthy and born full-term. Fifteen additional infants were tested but eliminated from the experiment, eight because they looked the maximum time allowed during the pretest and test trials, six because of procedural error, and one because the primary observer was unable to follow the direction of the infant's gaze. Seven infants were randomly assigned to each of the eight groups formed by crossing age (4.5 or 7.5 months), object speed (immediate or normal reappearance), and test event (experimental or control): immediate-reappearance experimental ($M = 4$ months, 22 days; $M = 7$ months, 12 days); immediate-reappearance control ($M = 4$ months, 24 days; $M = 7$ months, 14 days); normal-reappearance experimental ($M = 4$ months, 21 days; $M = 7$ months, 16 days); and normal-reappearance control ($M = 4$ months, 24 days; $M = 7$ months, 19 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.

2.1.2. Apparatus

The apparatus was a wooden cubicle 213 cm high, 105 cm wide, and 43.5 cm deep. The infant sat facing an opening 51 cm high and 93 cm wide in the front wall of the apparatus. The floor of the apparatus was covered with cream contact paper and the side walls were painted off-white. The back wall was covered with wood-grain contact paper. A 14 cm square hole in the back wall, centered between the right and left walls and flush with the floor of the apparatus, was concealed with a door covered with wood-grain contact paper. A platform 1.5 cm high, 91 cm wide, and 20 cm deep covered with cream contact paper lay centered between the left and right walls and flush with the back wall. A 12.5 cm deep strip of light blue flannel lay centered down the length of the platform.

The columns were made of alternating rows of red, yellow, and blue Duplos and were 12 cm high, 6 cm wide, and 3 cm deep. They were mounted on a piece of Plexiglas 0.3 cm high, 6 cm wide, and 3 cm deep.

Two screens were used in the immediate-reappearance conditions. The first screen was 24 cm high and 35 cm wide and mounted in two metal clips attached to a wooden dowel. The ends of the dowel exited the apparatus through small holes in the right and left walls. By rotating the dowel's right end (out of the infant's view), the screen could be lowered to lay flat on the apparatus floor. The second screen, used only in the control condition, was 18 cm high and 33 cm wide (and thus sufficiently tall to hide a second column). A wooden base attached to the floor held this screen upright behind the first (rotating) screen. Both screens were made of cardboard and covered with dark green contact paper. Two screens were also used in the normal-reappearance conditions, and these screens differed from those used in the immediate-reappearance conditions only in their width: the first screen was 24 cm wide and the second screen 22 cm wide.

A muslin-covered curtain was lowered after each trial to cover the opening in the front wall of the apparatus. Two muslin-covered frames, each 213 cm high and 68 cm wide, stood at an angle on either side of the apparatus. These frames isolated the infant from the experimental room. Observers watched the infant through dime-sized holes that were covered with gauze. In addition to the room lighting, four 20-W fluorescent bulbs (60 cm long in front and back and 30 cm long on each side) were attached to the walls of the apparatus.

2.1.3. Events

Three experimenters worked together to produce the pretest and test events. The first two experimenters wore white elbow-length gloves on their right hands and arms and manipulated the objects. A third experimenter operated the screen. All three experimenters followed a precise script, using a metronome that ticked softly once per second. In the following text, the numbers in parentheses indicate the time taken to produce the actions described. Prior to the experiment, the first experimenter showed her gloved hand to the infant.

2.1.3.1. Immediate-reappearance experimental condition. The infants first saw two *pretest* trials designed to acquaint them with the column, screen, and platform. At the start of the first pretest trial, the screen stood upright at the center of the platform. The first experimenter's right hand held the column from the top, 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 trial ended. The center of the column (when upright) was 6 cm from the left edge of the screen. In the second pretest trial, the hand held the second column to the right of the screen and tilted it gently until the end of the trial.

At the start of the *test* trial, the first experimenter tilted the column gently to the left and right, as before. The second experimenter held the second column in her right hand, out of the infant's view, behind the right half of the screen. When the computer signaled that the infant had looked at the display for 2 cumulative seconds, the *initial phase* of the test event began. The first experimenter held the column upright (1 s), and then moved it to the right at a rate of 3 cm/s until it was fully occluded by the screen (2.5 s). Immediately after the first column became fully occluded, the second experimenter moved the second column from behind the right edge of the screen (the two experimenters had similar sized hands covered by identical white gloves) until its center was 6 cm from the right edge of the screen (2.5 s).[3] The column was tilted gently left and right while the first experimenter surreptitiously removed the first column from behind the screen (2 s) and the third experimenter lowered the screen (1 s). During the *final phase*, the first experimenter gently tilted the column to the right of the screen; the area behind the screen was empty.

During the initial phase of the test event, the total length of the two columns' trajectories from left to right was 47 cm and the occlusion time was less than 0.5 s.

2.1.3.2. Immediate-reappearance control condition. The infants in the immediate-reappearance control condition saw the same pretest and test events as the infants in the immediate-reappearance experimental condition with one exception: the shorter screen stood behind the rotating screen, blocking the infants' view of the central portion of the platform during the final phase of the test event.

2.1.3.3. Normal-reappearance experimental condition. The infants in the normal-reappearance experimental condition saw the same pretest events as the infants in the immediate-reappearance experimental condition. To equate the immediate- and normal-reappearance test events as much as possible, we chose to hold constant the duration of the entire event cycle seen in the initial phase (9 s) and the amount of time the objects were seen in motion during that time (5 s). If the same speed of motion and test screen had been used in the normal- and immediate-reappearance events, but the columns had remained occluded for the time appropriate for a constant rate of motion, the whole event cycle would have been approximately 19.7 s, the total motion of the columns 15.7 s, and the columns would have been out of view for 9.7 s. We were concerned that the infants might respond differently during the final phase simply because the event seen in the initial phase was so much longer in duration and less interesting to watch (the objects were out of view for almost half of the event). Hence, the infants in the normal-reappearance experimental condition saw test events that were similar in overall duration to the test events shown to the infants in the immediate-reappearance experimental condition, but that differed in the following ways: (a) the columns seen to each side of the screen traveled at a speed of 12 cm/s; (b) the immediate-reappearance test screen was replaced with the test screen that was more narrow; and (c) the occlusion interval was appropriate for a constant rate of motion. Because the columns moved more quickly when in view, it was also necessary to increase the length of each column's trajectory. At the start of each trial, the left column stood with its center 18 cm from the left edge of the screen. During the initial phase of the test event, the total length of the two columns' trajectories was 60 cm and the occlusion time was 1.5 s.

2.1.3.4. Normal-reappearance control condition. The infants in the normal-reappearance control condition saw the same pretest and test events as the infants in the normal-reappearance experimental condition with one exception: the shorter screen stood behind the rotating screen, blocking the infants' view of the central portion of the platform during the final phase of the test event.

2.1.4. Procedure

Each infant sat on a parent's lap centered in front of the apparatus. The infant's head was approximately 80 cm from the platform. Parents were instructed not to interact with their infant while the experiment was in progress and to close their eyes during test.

The infants received two pretest trials followed by one test trial. The pretest trials ended when the infant either (a) looked at the display for a maximum of 60 cumulative seconds or (b) looked away for 2 consecutive seconds after looking a minimum of 5 cumulative seconds. Looking times during the initial and final phases of the test trial were recorded separately; only the looking times obtained during the final phase were analyzed. This phase ended when the infant either (a) looked at the display for a maximum of 60 cumulative seconds or (b) looked away for 1 consecutive second after looking a minimum of 4 cumulative seconds.

To ensure that the experimenters followed the events' scripts precisely, in this and the following experiments, a camera was placed directly behind and above the parent's head, providing a head-on view of the event as it occurred. The first and second experimenters monitored the event on a video screen that could be seen by both experimenters but not the observers. If a procedural error was detected (e.g., the second object emerged before the first object became fully occluded or the second object failed to appear immediately), that infant's data were eliminated from the analysis.[4]

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, which event (experimental or control) each infant saw.[5] Each observer held a button connected to a computer and depressed the button when the infant attended to the events. The looking times recorded by the primary observer determined when a trial had ended and were used in the data analyses. Each trial was divided into 100 ms intervals, and the computer determined in each interval whether the two observers agreed on the direction of the infant's gaze. Interobserver agreement was measured for 17 of the 24 infants (for the other 7 infants only 1 observer was present) and was calculated for each test trial by dividing the number of intervals in which the computer registered agreement by the total number of intervals in the trial. Agreement averaged 91% per trial per infant.

2.2. Results

2.2.1. Preliminary analyses

Preliminary analyses were conducted for each of the experiments reported in this article to explore whether males and females responded differently to the test events. These analyses failed to reveal reliable sex differences. Hence, in this and the following experiments, the data were collapsed across sex. However, because of the small number of infants in each cell for each analysis, these results need to be interpreted with caution.

2.2.2. Pretest trials

The infants' looking times during the two pretest trials were averaged and analyzed by means of a $2 \times 2 \times 2$ ANOVA with age (4.5 or 7.5 months), object speed (immediate or normal reappearance), and test event (experimental or control) as between-subjects factors. The main effects of age, object speed, and test event were not significant, all $F(1, 48)\text{s} < 1$.

In addition, there were no significant interactions involving these factors, all $F(1, 48)$s < 1, indicating that the 4.5-month-olds (immediate-reappearance experimental, $M = 31.8$, SD $=$ 11.4; immediate-reappearance control, $M = 31.4$, SD $= 22.2$; normal-reappearance experimental, $M = 33.5$, SD $= 18.2$; normal-reappearance control, $M = 31.9$, SD $= 20.6$) and the 7.5-month-olds (immediate-reappearance experimental, $M = 32.8$, SD $= 16.8$; immediate-reappearance control, $M = 37.0$, SD $= 14.6$; normal-reappearance experimental, $M = 33.8$, SD $= 11.8$; normal-reappearance control, $M = 26.7$, SD $= 13.3$) in the four conditions did not differ reliably in their mean looking times during the pretest trials.

2.2.3. Test trials

The infants' looking times during the final phase of the test trial (Fig. 3) were analyzed in the same manner as in the pretest trials. The main effect of age was not significant, $F(1, 48) <$ 2. However, the main effects of object speed, $F(1, 48) = 4.46$, $p < .05$, and test event, $F(1, 48) = 11.36$, $p < .01$, were significant, as was the Object Speed × Test Event interaction, $F(1, 48) = 11.8$, $p < .01$. All other interactions were not significant, $F(1, 48)$s < 2. Planned contrasts revealed that in the immediate-reappearance condition, the experimental infants ($M =$ 33.5 s, SD $= 16.2$) looked reliably longer at the final display than did the control infants ($M =$ 11.5 s, SD $= 6.5$), $F(1, 48) = 23.15$, $p < .001$. In contrast, in the normal-reappearance condition, the infants who saw the experimental ($M = 15.6$ s, SD $= 10.1$) and control ($M =$ 15.8 s, SD $= 13.2$) events looked about equally at the final display, $F(1, 48) < 1$. Finally,

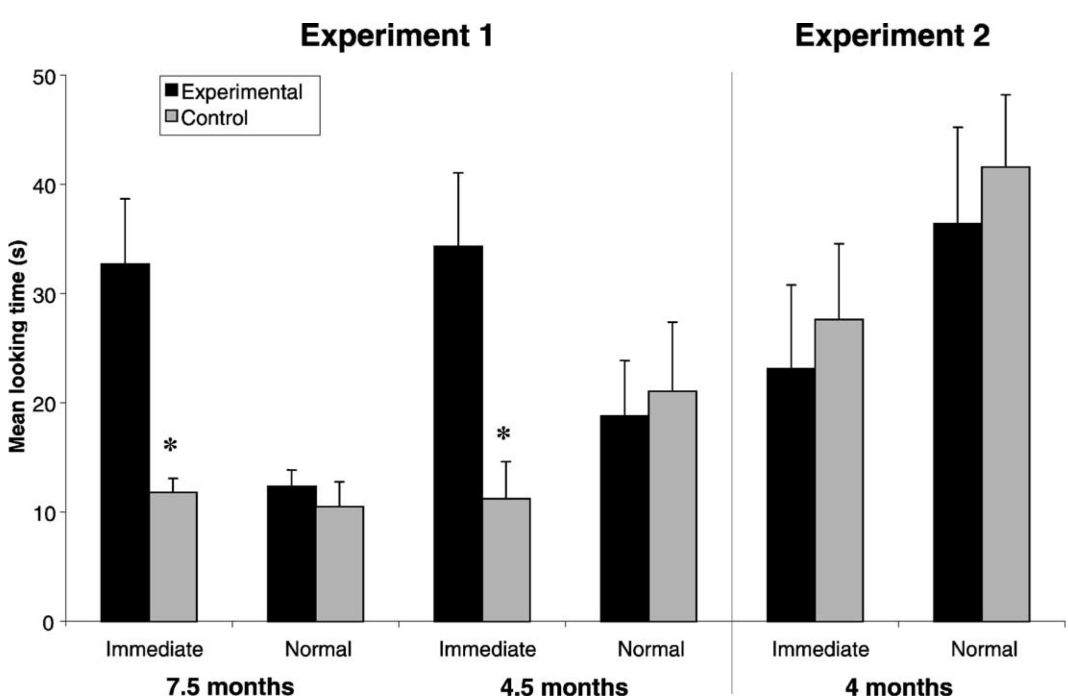

Fig. 3. Mean looking times (and standard errors) of the 7.5- and 4.5-month-olds of Experiment 1 and the 4-month-olds of Experiment 2 during the final phase of the test events.

the looking times of the infants in the immediate- and normal-reappearance experimental conditions differed reliably from each other, $F(1, 48) = 15.35$, $p < .001$.

To assess whether these differences were reliable for both age groups, additional planned contrasts were conducted for the 4.5- and 7.5-month-olds separately. For the 4.5-month-olds, the infants in the immediate-reappearance condition looked reliably longer at the experimental ($M = 34.3$ s, SD $= 17.8$) than at the control ($M = 11.2$ s, SD $= 9.0$) test event, $F(1, 48) = 12.78$, $p < .001$. In contrast, the infants in the normal-reappearance condition looked about equally at the experimental ($M = 18.8$ s, SD $= 13.5$) and control ($M = 21.1$ s, SD $= 16.7$) events, $F < 1$. The same pattern was found for the 7.5-month-olds: the immediate-reappearance infants looked reliably longer at the experimental ($M = 32.7$ s, SD $= 15.8$) than at the control ($M = 11.8$ s, SD $= 3.4$) test event, $F(1, 48) = 10.46$, $p < .01$, whereas the normal-reappearance infants looked about equally at the experimental ($M = 12.4$ s, SD $= 3.8$) and control ($M = 10.5$ s, SD $= 6.0$) events, $F(1, 48) < 1$.

2.3. Discussion

The 4.5- and 7.5-month-olds in the immediate-reappearance experimental condition looked reliably longer at the final display than did those in the control condition. These results suggested the infants (a) were led by the speed discontinuity in the initial phase of the event to infer that two distinct columns were involved in the event; (b) expected to see two columns when the screen was lowered; and (c) were puzzled, in the experimental condition, when this expectation was violated (in the control condition the second column could have been hidden behind the shorter screen). This interpretation was supported by the results obtained in the normal-reappearance experimental and control conditions. The infants in these conditions tended to look about equally at the final display, suggesting that they (a) assumed, as they watched the initial phase of the event, that the columns shown to the left and the right of the screen were one and the same column and (b) found their interpretation of the normal-reappearance event consistent with there being a single column on the platform (the presence of the shorter screen behind the lowered screen became irrelevant).

What assurance do we have that the infants were responding based on inferences made about the number of objects present in the event, rather than to superficial differences between the events? Remember that the *only* difference between the immediate-reappearance experimental and control conditions was whether the platform was occluded by a shorter screen during the final phase of the test event; this was also the *only* difference between the normal-reappearance experimental and control conditions. If the infants in the immediate-reappearance experimental condition looked longer at the final display simply because they found one screen display more interesting than another, then the infants in the normal-reappearance experimental condition should also have looked longer at the final display, and they did not.

Together, these results suggest that by 4.5 months infants not only attend to speed discontinuities, but use such discontinuities to draw conclusions about the number of objects present in an event. What is left open to speculation is why the 4.5-month-olds in the present experiment demonstrated this ability but the 4-month-olds tested by Spelke et al. (1995) did not. There are two possible explanations for these results. The first has to do with the method that was used to assess infants' sensitivity to speed information. Recall that in Experiment 1, a modified version of the Spelke et al. (1995) task was used. Perhaps the modifications that were made to Spelke et al.'s procedure rendered the task more sensitive to the abilities it was designed to tap. The second has to do with the age of the infants tested; slightly older infants were tested in Experiment 1. There is evidence that young infants' responses to occlusion events change rapidly during the first months of life, so that infants differing in age by only a few weeks often perform quite differently on the same task (e.g., Aguiar & Baillargeon, 1999, 2002; Wilcox & Schweinle, 2002). Perhaps the discrepancy in the results described above reflects developmental changes in infants' ability to interpret occlusion events with speed discontinuities. The next experiment tested these two possibilities.

3. Experiment 2

Experiment 2 was conducted to determine whether the 4.5-month-olds tested in Experiment 1 succeeded because they were tested using a slightly different task than that used by Spelke et al. (1995) or because they were somewhat older than the infants tested by these authors. Infants 4 months of age were assigned to the two immediate-reappearance (experimental or control) and normal-reappearance (experimental or control) conditions of Experiment 1.

3.1. Method

3.1.1. Participants

Participants were 28 4-month-olds, 14 male and 14 female ($M = 4$ months, 5 days; range $= 4$ months, 0 days to 4 months, 12 days). Four additional infants were tested but eliminated, two because the infant looked the maximum time allowed during the pretest and test trials, one because of procedural problems, and one because the primary observer was unable to follow the direction of the infant's gaze. Seven infants were randomly assigned to each of the four conditions: immediate-reappearance experimental ($M = 4$ months, 4 days), immediate-reappearance control ($M = 4$ months, 3 days), normal-reappearance experimental ($M = 4$ months, 5 days), and normal-reappearance control ($M = 4$ months, 8 days).

3.1.2. Apparatus, events, and procedure

The apparatus, events, and procedure used in Experiment 2 were identical to those of Experiment 1. Interobserver agreement was measured for 23 of the 24 infants and averaged 95%.

3.2. Results

3.2.1. Pretest trials

The infants' looking times during the two pretest trials were averaged and analyzed by means of a 2×2 ANOVA with object speed (immediate or normal reappearance) and test event (experimental or control) as between-subjects factors. The main effects of object speed and test event were not significant, both $F(1, 24)$s < 1, and neither was the Object Speed $\times$ Test Event interaction, $F(1, 24) < 1$. The infants in the four conditions thus did not differ reliably in their mean looking times during the pretest trials (immediate-reappearance experimental, $M = 42.3$, SD $=$ 21.2; immediate-reappearance control, $M = 42.5$, SD $=$ 17.8; normal-reappearance experimental, $M = 39.8$, SD $=$ 19.6; normal-reappearance control, $M = 40.9$, SD $=$ 12.2).

3.2.2. Test trials

The infants' looking times during the final phase of the test trial (Fig. 3) were analyzed in the same manner as in the pretest trials. The main effects of object speed, $F(1, 24) = 3.24$, $p > .05$, and test event, $F(1, 24) < 1$, were not significant, nor was the Object Speed $\times$ Test Event interaction, $F(1, 24) < 1$. The infants in the four conditions thus did not differ reliably in their mean looking times during the final phase of the test trial (immediate-reappearance experimental, $M = 23.2$, SD $=$ 20.2; immediate-reappearance control, $M = 27.6$, SD $=$ 18.4; normal-reappearance experimental, $M = 36.4$, SD $=$ 23.4; normal-reappearance control, $M = 41.6$, SD $=$ 17.5).

3.3. Discussion

The looking times of the infants in the immediate-reappearance experimental condition did not differ reliably from those of the infants in the control condition, suggesting that the experimental infants did not detect a discrepancy between the immediate-reappearance event, shown in the initial phase of the test trial, and the one-column display, shown in the final phase. These results are consistent with those reported by Spelke and her colleagues (Spelke et al., 1995), and indicate that even when tested with a simpler version of the Spelke et al. task, 4-month-olds still fail to demonstrate the ability to use speed of motion as the basis for object individuation.

Current findings in the object individuation literature (Wilcox & Baillargeon, 1998a) led us to question, however, whether the negative results obtained with the 4-month-olds might be a function of the type of task used. There is evidence that some types of tasks provide more sensitive tests of infants' capacity to individuate objects than do other tasks (e.g., Wilcox, 1999; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Schweinle, 2002; for a review see Wilcox, Schweinle, & Chapa, 2003).

Two general types of tasks have been used to assess object individuation in infancy: event-mapping and event-monitoring tasks (see Wilcox & Baillargeon, 1998a). In an *event-mapping* task, infants see an occlusion event involving one or two objects, the screen is removed, and then infants are shown a display containing one or two objects. In order to succeed on an event-mapping task, infants must (a) retrieve their representation of the occlusion event; (b) compare it to the one- or two-object display before them; and (c) judge whether the two are congruent. This is the type of task used in Experiments 1 and 2, and the type of task used by Spelke and her colleagues (Spelke & Kestenbaum, 1986; Spelke et al., 1995). In an *event-monitoring* task, infants see only one event, an occlusion event, involving either one or two objects; infants must judge whether successive portions of the event are consistent. In general, infants are more likely to produce successful performances when tested with an event-monitoring as opposed to an event-mapping task (Hespos, 2000; Wilcox, 1999; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Schweinle, 2002; Wilcox et al., 2003), presumably because it is easier for infants to monitor the internal consistency of a single ongoing event than to map one event representation onto another.

The next experiment built on these findings by examining whether infants younger than 4.5 months of age might be more likely to demonstrate sensitivity to speed information if they were tested with an event-monitoring task.

4. Experiment 3

The infants in Experiments 1 and 2 saw the following occlusion sequence: (1) an object stood to the left of an upright screen; (2) the object moved behind the left edge of the screen; and (3) an identical object immediately appeared at the right edge of the screen. The results indicated that the 7.5- and 4.5-month-olds inferred that two distinct objects were involved in the event, one object that moved behind the left edge of the screen and a second identical object that emerged from behind the right edge. To interpret the event in this manner, the infants had to assume that the second object stood behind the right side of the screen. If the second object had *not* been present behind the right side of the screen at the beginning of the test trial, it would have been impossible for the object to emerge immediately on the right. No assumptions were required about the placement of the first object, as it started in full view to the left of the screen. The event-monitoring task used in Experiment 3 was designed to test infants' interpretation of the immediate-reappearance event by violating the assumption that a second object stood behind the right side of the screen.

Infants aged 3.5 months were assigned to one of two window-on-right conditions: experimental or control (Fig. 4). Infants in both conditions saw an occlusion sequence similar to the immediate-reappearance event used in Experiments 1 and 2 with three exceptions. First, a window was created in the right half of the screen. In the *experimental* condition, infants could see through the window, noting that the area behind the right half of the screen was empty. In the *control* condition, a second screen stood in the window, blocking the infants' view of the area behind it. Before the column began its motion a flap was the lowered to cover the window. Second, once in motion the columns remained in motion. After moving left-to-right across the platform the column reversed direction and the event was seen right-to-left. The entire event sequence then repeated until the end of the trial. Note that once the flap was lowered, the experimental and control test events were identical in appearance. Third, and most importantly, the screen remained upright throughout the test trial. Keeping the screen upright, so that infants saw only an occlusion situation (rather than an occlusion situation followed by a no-occlusion situation, as in Experiments 1 and 2) made this an event-monitoring task.

We reasoned that if the control infants (a) were led by the speed discontinuity to conclude that the event involved two identical columns and (b) realized that in order for the second column to emerge immediately it must have been standing behind the right edge of the screen, then they should assume that the column must have been hidden at the start of the trial behind the second screen in the window. The experimental infants, who had seen through the window that the area behind the right half of the screen was empty, should not be able to explain the immediate reappearance of the column, and they should therefore respond with increased attention. We thus expected the infants in the experimental condition to look reliably longer at the test event than the infants in the control condition.

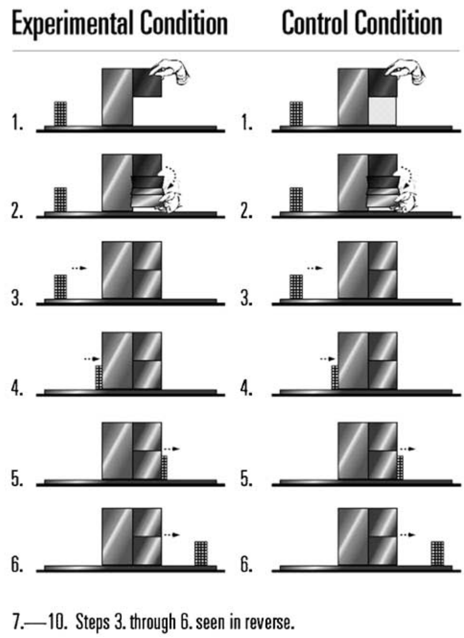

Fig. 4. Schematic drawing of the test events in the window-on-right experimental and control conditions of Experiment 3.

It is possible, however, that the infants in the experimental condition might look longer at the test event for another reason. For example, the infants might find the open window shown at the start of the trial very intriguing. Continued interest in the area behind the window, even once the window was covered, could lead to increased looking times during the test event. To control for this possibility, additional infants were assigned to one of two window-on-left conditions: experimental or control. Infants in the window-on-left conditions saw the same test events as infants in the corresponding window-on-right conditions (experimental or control) with one difference: the window was placed in the left, rather than the right, half of the screen. If the infants in the window-on-right experimental condition looked longer at the test event simply because they were intrigued by the "window with a view," then the infants in the window-on-left experimental condition should also evidence prolonged looking at the test event. In contrast, if the infants in the window-on-right experimental condition looked longer at the test event because they were puzzled that the area behind the right half of the screen had been revealed as empty, then the infants in the window-on-left experimental condition, who were shown instead the area behind the left half of the screen (and hence could still assume that a second object stood behind the right half), should not find the test event surprising.

There were two main procedural difference between Experiment 3 and the previous experiments. First, handles were attached to the back of the objects, which were now moved from behind the apparatus, out of the infants' view. Hence, from the infants' point of view the objects were self-moving. Because an immediate-reappearance event is physically impossible regardless of whether an object is self-moving or moved by a hand, this procedural difference was not considered problematic to the interpretation of the results. Second, the infants were given familiarization trials. There is evidence that infants have difficulty building representations of occlusion events that involve self-moving objects if they are not first familiarized with the objects (see Baillargeon, 1995).

4.1. Method

4.1.1. Participants

Participants were 24 3.5-month-old infants, 12 male and 12 female ($M = 3$ months, 21 days; range = 3 months, 12 days to 3 months, 28 days). Seven additional infants were eliminated from the experiment, four because of procedural problems, two because of fussiness or crying, and one because the primary observer was unable to follow the direction of the infant's gaze. Six infants were randomly assigned to each of four groups formed by crossing test event (experimental or control) with window location (right or left): experimental window-on-right condition ($M = 3$ months, 20 days); control window-on-right condition ($M = 3$ months, 22 days); experimental window-on-left condition ($M = 3$ months, 22 days); control window-on-left condition ($M = 3$ months, 21 days).

4.1.2. Apparatus

The apparatus used in Experiment 3 was identical to that of Experiment 1 with one exception. In order for the experimenter to lower the flap on the test screen at the beginning of each test trial, openings 20 cm wide and 25.5 cm tall were created in the right and the left walls of the apparatus, for the window-on-right and window-on-left conditions, respectively. When in use, the openings were masked with cream-colored fringe. When not in use, the openings were covered with hinged doors.

The screen used in the familiarization event was 27 cm high and 30 cm wide, made of cardboard, painted orange, and held upright by a wooden base attached to the apparatus floor. The screen used in the window-on-right test event was 30 cm high and 30 cm wide, made of cardboard, and covered in blue contact paper with gold stars and swirls. A window, 15 cm high and 13 cm wide, was cut in the bottom right-hand corner of the screen. A flap 15 cm high and 13 cm wide could be lowered to covered the window opening. The screen was held upright by a metal L-shaped foot that was attached to the back of the screen and slid under the platform. The screen used in the window-on-left test event was identical to the one used in the window-on-right test event except that the window was located in the bottom left-hand corner of the first screen. In either condition, the second screen used to occlude the window was 16.5 cm high and 15 cm wide, made of cardboard, and covered with blue contact paper.

Two identical objects were used to produce the event. They were columns 12 cm high, 6 cm wide, and 6 cm deep, made of Styrofoam, and covered in red- and white-checked fabric. The columns were mounted on a piece of Plexiglas 0.3 cm high, 6 cm wide, and 6 cm deep. A wooden handle 7 cm in diameter extended from the back center of the columns and exited the apparatus through a slit 7 cm high and 32 cm along in the back wall. The slit was concealed from the infants by cream-colored fringe. Using the handle, the experimenter could move the columns left and right along the platform.

4.1.3. Events

Two experimenters wearing white gloves worked together to produce the familiarization and test events. The first experimenter moved the columns along the platform; the second experimenter operated the screen and manipulated the second column behind the screen. The numbers in parentheses indicate the time taken to produce each of the actions described. A metronome ticked softly once per second to help the experimenters adhere to the events' scripts.

4.1.3.1. Window-on-right experimental condition. At the start of each *familiarization* trial, the first column sat with its center 6 cm from the left edge of the screen; the screen stood upright and centered on the platform. The second column sat behind the left half of the screen (to be consistent with the test event, described below, the second column started behind the left half of the screen and was then moved). At the end of the pretrial (when the computer signaled that the infant had looked at the display for 2 cumulative seconds), the first column remained stationary briefly (1 s) while the second experimenter surreptitiously inserted the second column, through the opening in the back wall, and placed it behind the right half of the screen. Next, the first column moved to the right at a rate of 3 cm/s until it was fully occluded by the screen (2.5 s); the second column immediately appeared at the right edge of the screen and moved until its center was 6 cm from the right edge of the screen (2.5 s). The immediate-reappearance event was then seen in reverse. Each event cycle thus lasted 12 s; cycles were repeated until the end of the trial.

The *test* event was identical to the familiarization event with the following exceptions. First, the orange familiarization screen was replaced with the blue test screen with the window on the right. Second, at the start of the test event the second experimenter, whose arm entered the apparatus through an opening in the right wall, held the window flap in its raised position, revealing the empty window. At the end of the pretrial (when the computer signaled that the infant had looked at the display for 4 cumulative seconds) the second experimenter lowered the flap to cover the window (1 s) and removed her hand from the apparatus (2 s). From this point on, the event preceded exactly as the familiarization event, starting after the pretrial.

In both the familiarization and test trials, the length of the columns' trajectories from left to right was 42 cm and the occlusion time was less than 0.5 s.

4.1.3.2. Window-on-right control condition. The familiarization and test events shown in the window-on-right control condition were identical to those in the window-on-right experimental condition with one exception: in the test event the second screen stood behind the open window, occluding the infant's view of the platform behind.

4.1.3.3. Window-on-left experimental condition. The familiarization and test events shown in the window-on-left experimental condition were identical to those in the window-on-right experimental condition with two exceptions: (a) in the test event, the window was located in the left half of the screen and (b) the second column sat behind the right half of the screen at the beginning of the familiarization and test trials.

4.1.3.4. Window-on-left control condition. The familiarization and test events shown in the window-on-left control condition were identical to those in the window-on-left experimental condition with one exception: in the test event, the second screen was used to occlude the open window.

4.1.4. Procedure

Each infant participated in a two-part procedure that consisted of familiarization and test trials. During the *familiarization* part, all infants saw the same event on six successive trials. The familiarization trials ended when the infants either (a) looked at the display for a maximum of 60 cumulative seconds or (b) looked away for 2 consecutive seconds after looking a minimum of 12 s (the duration of the first full event cycle, starting after the pretrial). During the *test* part, the infants saw the test event appropriate for their condition on two successive trials. Each test trial ended when the infants either (a) looked at the display for a maximum of 60 cumulative seconds or (b) looked away for 1 consecutive seconds after looking a minimum of 9 s (the time it took the column to first reach the end of the platform, starting after the pretrial and before the flap was lowered).

Interobserver agreement was measured for 17 of the 24 infants and averaged 91% per test trial per infant.[6]

4.2. Results

4.2.1. Familiarization trials

The infants' looking times during the six familiarization trials were averaged and analyzed by means of a 2 × 2 ANOVA with window location (right or left) and test event (experimental or control) as between-subjects factors. The main effects of window location and test event were not significant and the Window Location × Test Event interaction was not significant, all $F(1, 20)$s < 1, indicating that the infants in the different conditions did not differ reliably in their mean looking times during the familiarization trials (window-on-right experimental, $M = 41.5$ s, SD $= 10.9$; window-on-right control, $M = 37.2$ s, SD $= 12.9$; window-on-left experimental, $M = 37.0$ s, SD $= 11.2$; window-on-left control, $M = 36.9$ s, SD $= 11.9$).

4.2.2. Test trials

The infants' looking times during the two test trials (Fig. 5) were averaged and analyzed in the same manner as the familiarization trials. The main effects of window location, $F(1, 20) < 1$, and test event, $F(1, 20) = 4.11$, $p > .05$, were not significant. However, the Window Location × Test Event interaction was significant, $F(1, 20) = 4.64$, $p < .05$. Planned comparisons indicated that in the window-on-right condition the experimental infants ($M = 40.1$ s, SD $= 17.1$) looked reliably longer at the test event than did the control infants ($M = 18.9$ s, SD $= 6.9$), $F(1, 20) = 8.76$, $p < .05$; in contrast, no reliable difference was found between the looking times of the infants in the window-on-left experimental ($M = 28.3$ s, SD $=$ 12.5) and control ($M = 28.9$ s, SD $= 10.9$) conditions, $F(1, 20) < 1$. Finally, the looking times of the infants in the window-on-right experimental condition were compared to those of the infants in the other three conditions and the difference was reliable, $F(1, 20) = 6.34$, $p < .025$.

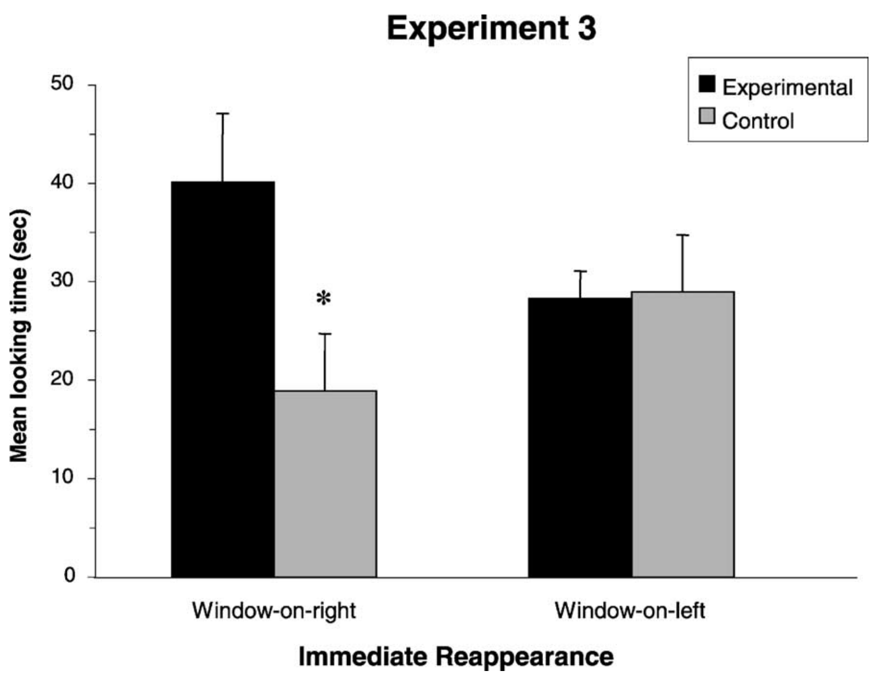

Fig. 5. Mean looking times (and standard errors) of the 3.5-month-olds of Experiments 3 during the test events.

4.3. Additional results

The positive results obtained in Experiment 3 suggested that the infants (a) realized that the columns seen to the left and the right of the screen were separate and distinct objects and (b) understood that in order for the column on the right to emerge immediately it must have been standing behind the right half of the screen. In other words, the infants not only expected a second object to be hidden behind the screen; they expected the second object to be positioned behind the *right* side of the screen. (Remember that in both the window-on-right and window-on-left conditions there was room for a second object behind the screen. The crucial difference between the two conditions was whether the second object could be behind the right side of the screen.) This interpretation of the data predicts that if infants were shown an event that did not require the presence of a second object, an event that could be produced with a single object, they would not find the right empty window puzzling. To test this prediction, infants' response to an event in which the object was occluded for an interval appropriate for its rate of motion was assessed.

Twelve 3.5-month-olds, six male and six female ($M = 3$ months, 22 days, range $= 3$ months 15 days to 3 months, 29 days) were randomly assigned to one of two normal-reappearance window-on-right conditions: experimental ($M = 3$ months, 23 days) or control ($M = 3$ months, 20 days). The infants in the normal-reappearance window-on-right experimental and control conditions saw the same familiarization and test events as the infants in the immediate-reappearance window-on-right experimental and control conditions, respectively, with one exception: as the column moved back and forth behind the screen it was occluded for an interval appropriate for its rate of motion. To create the normal-reappearance event, the strategy used in Experiment 1 was employed. First, the total duration of the event cycle (12 s), starting after the pretrial, and the amount of time the columns were in motion during that time (10 s) were held constant. Second, the column's speed of motion when visible, the width of the screen, and the occlusion interval were altered: the column moved more quickly (12 cm/s) behind a screen that was narrower (20.5 cm) and the column was occluded for a period of time appropriate for its rate of motion (approximately 1.2 s). This also required that the length of the trajectory be increased, so that at the start of each trial the column sat with its center 19.75 cm from the left edge of the screen. The total length of the objects' trajectories from left to right was 60 cm. Interobserver agreement was measured for 11 of the 12 infants and averaged 94%.

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, $F(1,\ 10) < 1$, indicating that there was no reliable difference between the looking times of the infants in the experimental ($M = 37.9$ s, $SD = 8.3$) and the control ($M = 34.6$ s, $SD = 10.8$) conditions at the familiarization event.

The infants' mean looking times during the two test trials were averaged and analyzed in the same manner as the familiarization trials. The main effect of condition was not significant, $F(1,\ 10) < 1$, indicating that there was no reliable difference between the looking times of the infants in the experimental ($M = 31.7$ s, $SD = 17.2$) and control ($M = 36.3$ s, $SD = 14.3$) conditions at the test event. These results suggested that the infants (a) assumed that only a single column was involved in the normal-reappearance event and, hence, (b) were not puzzled by the fact that the open window had been empty at the beginning of the test trial. Together, these results provide converging evidence for the conclusion that young infants, like adults, use speed of motion to draw inferences about the number of objects present in an occlusion event.

4.4. Discussion

In Experiment 3, the infants in the window-on-right experimental condition looked reliably longer at the immediate-reappearance test event than did the infants in the window-on-right control condition. These results suggested that the infants (a) understood that the column that disappeared at the left edge of the screen could not be the same column that appeared at the right edge and (b) were puzzled when they possessed information contradicting the notion that a second column stood behind the right half of the screen. This interpretation was supported by data obtained in two additional conditions that were identical to the first two conditions except that the window was placed in the left half of the screen. When the window was on the left, rather than on the right, the infants in the experimental and control conditions looked about equally at the immediate-reappearance event. These results suggested that it was not the empty window per se that the infants found intriguing, but the fact that the empty window on the right was inconsistent with the immediate reappearance of the column to the right of the screen.

What we are suggesting, then, is that the infants were led by the speed discontinuity in the immediate-reappearance event to *posit* the presence of a second object, an object that was not only numerically distinct from the first object but that followed a different trajectory behind the screen. When the test event as a whole was consistent with a two-object interpretation of the immediate-reappearance event, the infants did not find the test event anomalous. However, when given information inconsistent with a two-object interpretation (i.e., the infants had seen that there was no second object behind the right half of the screen), the infants were left without an explanation for how the test event was produced and they found it puzzling. Support for this interpretation was obtained in an additional experiment in which the object was occluded for an interval appropriate for its rate of motion. When the test event could be produced with a single object, the infants responded as if they did not find the empty window on the right unexpected. These findings confirm other recent reports that young infants cannot only represent the existence of occluded objects, but can also posit the existence of occluded objects to make sense of events that might otherwise appear anomalous (see Aguiar & Baillargeon, 2002 for a detailed discussion of this issue; Spelke & Kestenbaum, 1986; Spelke et al., 1995; Wilcox & Schweinle, 2002).

This analysis makes an interesting prediction. If 3.5-month-olds are capable of generating an explanation for the immediate-reappearance event, then they should not find that event, in and of itself, surprising. That is, infants should not be puzzled to see the object emerge immediately to each side of the screen. How likely is it that we would find support for this prediction? Consider a recent experiment conducted by Aguiar and Baillargeon (2002). Infants aged 3.5 months saw a test event in which a toy mouse moved back and forth behind a screen with a window. In a *high window* 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 a *low window* 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 about equally at the two test events, as if they did not find the mouse's failure to appear in the low window unexpected. Additional results suggested, however, that the infants failed to find the low window event surprising because they posited the presence of a second object. When the infants were shown, at the beginning of each trial that only one object was present in the apparatus, and hence could no longer generate a two-object explanation for the mouse's failure to appear in the window, they responded as though they found the low-window test event unexpected.

One way to test the prediction that infants would not find an immediate-reappearance event surprising was to compare the responses of the 3.5-month-olds who saw the immediate- and normal-reappearance events during the familiarization trials (averaged over the six trials), before the window was placed in the screen. This comparison revealed that the infants who saw the immediate-reappearance ($N = 24$, $M = 38.1$; SD $= 11.2$) and the normal-reappearance ($N = 12$, $M = 36.2$; SD $= 9.4$) event looked about equally during the familiarization trials, $t(26) < 1$ (a Satterthwaite df correction was used because of unequal cell sizes).

What remains open to interpretation is why the 3.5-month-olds in Experiment 3 successfully used speed of motion to draw conclusions about the number of objects present in an occlusion event, whereas the 4-month-olds in Experiment 2 and in Spelke et al. (1995) failed to demonstrate this ability. Possible reasons for the discrepancy in results will be offered in Section 5.

5. General discussion

The present research investigated the development of infants' ability to use speed information to individuate objects in occlusion events. Two different tasks were used to assess infants' sensitivity to speed of motion. In one task (i.e., an event-mapping task), the infants saw an occlusion event involving a speed discontinuity, the screen was lowered, and the infants saw a single object on the platform. Infants aged 7.5 and 4.5 months (Experiment 1) responded as if they (a) used the speed discontinuity to conclude that two objects were involved in the immediate-reappearance event and (b) realized that their representation of the immediate-reappearance event was inconsistent with the presence of a single object behind the screen. Converging evidence for this interpretation was obtained in a condition where the occlusion interval was appropriate for the objects' rate of motion. In contrast, 4-month-olds (Experiment 2) responded as if they did not detect a discrepancy between the immediate-reappearance event and the final one-object display. The negative results obtained with the younger infants are consistent with those previously obtained by Spelke and her colleagues (Spelke et al., 1995) using a similar task.

However, when a very different task (i.e., an event-monitoring task) was used, positive results were obtained with 3.5-month-olds (Experiment 3). The infants watched an event involving a speed discontinuity; the experiment examined whether the infants found this event puzzling after seeing an open and empty window in the right half of the screen or a closed window behind which a second object could have been hidden. The infants responded as if they (a) recognized that two objects were necessary to produce the event, one of which must be present behind the right half of the screen and (b) were puzzled when no such object had been present in the window prior to the test event. This conclusion was supported by data obtained in additional conditions in which (a) the window was in the left, rather than the right, half of the screen or (b) the object was occluded for an interval appropriate for its rate of motion.

5.1. The importance of speed of motion to infants' interpretation of occlusion events

The positive results obtained with the 7.5- and 4.5-month-olds in Experiment 1 and the 3.5-month-olds in Experiment 3 build on previous research in two ways. *First*, they add to a growing body of literature indicating that motion-carried information is fundamental to infants' and adults' perception of objects (e.g., Arterberry, 1997; Arterberry, Craton, & Yonas, 1993; Kellman, 1993). Most of this research has focused on the perception of fully or partly visible objects. For example, both infants and adults use discrepancies in speed or direction of motion to impose object boundaries (Gibson, 1966; Gibson, Gibson, Smith, & Flock, 1959; Granrud et al., 1984; Kaufman-Hayoz, Kaufman, & Stucki, 1986; Kaplan, 1969), to distinguish figure from ground (Craton, 1989), and to make judgments about whether surfaces are connected behind an occluder (Kellman & Spelke, 1983; Kellman, Spelke, & Short, 1986; Van de Walle & Spelke, 1996; Vicario & Kiritani, 1999). The present research is unique in that it demonstrates that infants rely on speed of motion to interpret visual displays when objects become fully occluded, so that the surfaces in question are seen successively rather than simultaneously. Even when perceptual contact is completely lost, making interpretation of the visual display more complicated, infants still successfully use object speed to make judgments about how many objects are present in an event.

Second, the present research indicates that from a very early age speed of motion, like path of motion (Aguiar & Baillargeon, 2002; Spelke et al., 1995), is important to the individuation process. It is probably not the case, however, that the kind of path discontinuity that we have discussed here (i.e., a spatiotemporal gap in path of motion) and speed discontinuities are equally salient as indicators of numerical identity. There is evidence, from a number of different laboratories, that infants 3.5 to 10 months of age consistently and reliably interpret a spatiotemporal gap in path of motion as involving two separate and distinct objects (Aguiar & Baillargeon, 2002; Spelke et al., 1995; Wilcox & Schweinle, 2002; Xu & Carey, 1996). In contrast, infants' capacity to interpret a discontinuity in speed of motion is not as clear. Although the infants in the present experiments responded as if they had concluded that the immediate-reappearance event involved two objects, there is evidence that some changed speed events are more difficult for infants and adults to interpret than others (Burke, 1952; Putthoff & Wilcox, 1997).

Infants' differential capacity to use these two kinds of information as the basis for object individuation may reflect, to at least some extent, the kinds of experiences infants have with motion-carried information. When watching objects move about in the world, infants see that objects' paths never contain gaps and never intersect with those of other objects (i.e., objects do not jump in space and time nor do they pass through other solid surfaces). When a disruption in path is observed, there is always a second object involved. Using the terminology of Aguiar and Baillargeon (1999), infants get good *contrastive evidence* about the relation between path of motion and numerical identity: a single continuous path suggests a single object, whereas a disrupted path indicates the presence of two objects. This leads infants to make strong and accurate predictions about object individuation based on path information.

In contrast, infants' experience with speed of motion is very different. Objects frequently alter their rate of motion and, most importantly, a discontinuity of speed is not routinely associated with more than one object. Hence, it is more difficult for infants to evaluate whether a change in speed signals the presence of a second object. What infants do see, however, is that when changes in object speed are smooth and gradual, one object is typically involved in the event, and that when changes in speed are very abrupt, so that they are physically impossible (i.e., an object would have to jump in space and time to reappear immediately at the opposite side of a wide screen), two objects are usually involved in the event. It makes sense then, that in the present experiments infants demonstrated sensitivity to the immediate-reappearance event: it was physically impossible for a single object to transverse the width of the screen in the time allotted.

Finally, there are probably other kinds of spatiotemporal discontinuities that could be used to individuate objects but, like speed of motion, are not definitive. For example, changes in direction of motion (e.g., Spelke, Katz, Purcell, Ehrlich, & Breinlinger, 1991) or alterations in the spatial orientation of an object (e.g., Hespos & Rochat, 1997; Rochat & Hespos, 1996) could be used to draw inferences about whether one or more than one object is present in an occlusion event. Under some conditions, these kinds of discontinuities might clearly suggest two objects; under other conditions such discontinuities would be more ambiguous in their interpretation.

5.2. Infants' sensitivity to speed discontinuities: How robust is it?

Are infants sensitive only to abrupt changes in object speed? How good are infants' at detecting and using speed discontinuities to interpret an occlusion event? Interpreting discontinuous-speed events requires the integration of several variables, including the object's rate of motion when visible, the width of the screen, and the time of occlusion. In the present experiments, the visible rate of motion was quite slow (3 cm/s), the occluder relatively wide (30 cm), and the occlusion interval extremely brief (<0.5 s). Under these conditions, the immediate-reappearance event was quite striking: the occlusion interval was simply too brief for the object to have traveled the width of the screen. What if the occlusion interval was not quite so brief? An experiment conducted by Putthoff and Wilcox (1997) examined whether infants would respond in the same way to an event in which the object appeared more quickly than predicted by its rate of motion, but not immediately. In this experiment 4- and 7.5-month-olds were first shown an object standing to the left of a lowered screen: the rest of the platform was empty, so that the infants could see that only a single object was present in the apparatus. The screen was then raised and infants saw the object move back and forth behind the screen. On some trials, the object emerged too quickly for its rate of motion, but the reappearance was not immediate. On other trials, the object emerged immediately to each side of the screen. When the object emerged immediately, the infants responded with increased looking, as if they found the immediate-reappearance event inconsistent with having seen a single object on the platform. In contrast, when the object reappeared too quickly for its rate of motion, but not immediately, the infants responded as if they did not find the changed-speed event anomalous. These results are consistent with reports from other investigators that tasks that require infants to track object speed through occlusion can be difficult for young infants to interpret (Arterberry, 1997; Oakes & Cohen, 1995).

Although we have not tested the effect of the other two variables, screen width and visible rate of motion, on infants' interpretation of changed-speed events, experiments conducted by Burke (1952) lead us to suspect that manipulation of these variables would also influence the individuation process. In his investigation of adults' response to changed-speed events, Burke (1952) found that observers were more likely to report the impression of two discrete object motions when viewing an immediate-reappearance event when the object moved slowly (6.2 cm/s) and the screen was wide (6 or 10 cm), at least relative to the width of the object (1 cm).[7] In cases where the object moved more quickly (30 or 60 cm/s), or the screen was more narrow (2.5 cm), adults reported experiencing a single object motion, rather than two distinct object motions, even when the occlusion interval was negligible. What is interesting, is that a different pattern of results was obtained when the occlusion interval was *longer* than predicted by the visible rate of motion. When the reappearance of the object was significantly delayed, adults also individuated the objects: they reported that one object stopped, and the other started, its motion behind the screen.

Together, these results suggest a general principle at work: the greater the discordance between the occlusion interval predicted by the object's rate of motion and the occlusion interval observed, the more likely it is that adults will report the perception of two objects. When objects move quickly and the screen is narrow, it is difficult to create a discordant immediate-reappearance event: the occlusion interval predicted by the object's rate of motion is not decidedly different from that which occurs when the object emerges immediately. In contrast, when the objects move more slowly and the screen is wide it is relatively easy to create a discordant immediate-reappearance event, since the expectation is that there would be a lengthy delay between the two perceptual encounters. (It is also the case that the greater the discordance, the more likely it is that the event violates physical laws. With a narrow screen, the object could reappear immediately if it had moved very fast behind the screen. In contrast, with a wide screen it may be physically impossible for the object to traverse the space in the time allotted, and one object cannot be in two places at the same time.) Although we suspect that the same principle influences infants' perception of changed-speed events, further investigation is needed to explore whether specific event parameters lead to similar event perceptions in infants and adults.

5.3. Explaining the discrepancy in performance: event monitoring and event mapping

At the same time that the present results indicate that young infants can use speed of motion to individuate objects, they also suggest that whether infants demonstrate this ability depends on the task used to assess it. These results echo what has been found in recent investigations of infants' use of featural information to individuate objects (Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Schweinle, 2002; Wilcox et al., 2003). Why, in the present experiments, did infants younger than 4.5 months succeed only when an event-monitoring task was used? It is difficult to draw firm conclusions about why the younger infants succeeded with one task and not the other, because there were so many differences between the two tasks. We would argue, however, that the crucial difference was whether infants saw two categorically distinct events (requiring them to map one event representation onto another) or only one kind of event (and had only to monitor the internal consistency of a single event).

There is recent evidence to support this interpretation of the results (Hespos, 2000; Wilcox & Chapa, 2002). For example, Wilcox and Chapa (2002) presented 9.5-month-olds with a two-phase task in which the final phase contained either a transparent occluder or no occluder at all. Hence, some infants saw an occlusion event (with an opaque occluder) followed by another occlusion event (with a transparent occluder), whereas other infants saw an occlusion event (with an opaque occluder) followed by a no-occlusion event (with no occluder). The entire event sequence progressed in the following way. During the initial phase of the test event, all infants saw a box (box–ball condition) or a ball (ball–ball condition) emerge from behind the left side of a screen and return; next, a ball emerged from behind the right side of the screen and returned. The center portion of the screen was then removed so that a frame, approximately 2.5 cm wide all the way around, remained standing. For half of the infants, a transparent pane was placed in the frame (occlusion condition); for the other infants, the frame was empty (no-occlusion condition). During the final phase of the test event infants in both conditions saw a single ball at the center of the platform. The results indicated that in the occlusion condition, the infants who saw the box–ball event looked reliably longer at the one-ball display than did the infants who saw the ball–ball event. In contrast, in the no-occlusion condition the infants who saw the box–ball and ball–ball events looked about equally at the final display. These results suggested that the infants (a) categorized the display involving the transparent occluder as the same sort of physical situation as the event involving the opaque occluder and (b) found it easier to demonstrate successful performance when they needed to reason only about one physical situation than when they were required to map categorically distinct situations.

5.4. Concluding remarks

The present research reveals the importance of speed information to infants' interpretations of occlusion events. At the same time, the results suggest that the task of individuating and representing objects within the context of occlusion events is not always an easy one for infants. The goal of future research is to explore, in more detail, developmental changes in the ability to individuate and representation objects and how these changes come about.

Notes

1. In the Burke (1952) experiments that object was 1 cm × 0.5 cm, the object's speed of motion ranged from 6.2 to 60 cm/s, the width of the occluder ranged from 2.5 to 70 cm, and the occlusion interval ranged from 7 to 700 ms.
2. In the Spelke et al. (1995) experiments, the cylinder was 7 cm × 19 cm and the screen 20 cm wide. In the constant-speed event, the object moved at a rate of 11 cm/s and was occluded for 1.2 s, an interval appropriate for its rate of motion. In the changed-speed and immediate-reappearance events the object moved at a rate of 3.5 cm/s and either appeared too quickly for its rate of motion (i.e., after a delay of 1.2 s) or immediately (after a delay of less than 1 s). In the one- and two-cylinder test events the cylinder(s) moved at a rate of 7.4 cm/s.
3. In the immediate-reappearance events reported herein, the object actually increased its speed slightly as it became occluded and disoccluded. For example, the object traveled a distance of 3 cm in 0.5 s when at each edge of the screen (i.e., it took the 6 cm wide object 0.5 s to go from being 50% occluded to fully occluded and 0.5 s to go from fully occluded to 50% disoccluded). Informal reports by adult viewers indicated that the immediate-reappearance event was more pronounced with this alteration, even though the observers were unable to detect the slight change in the objects' speed at each edge of the screen.
4. One might be concerned that the second experimenter, who held the object during the final phase of the test event, produced the event in a way that would bias the results. Several precautions were taken to ensure that the final phase of the test was presented uniformly across conditions in this and the subsequent experiment. First, although the second experimenter was not blind to the experimental condition to which each infant was assigned, she was blind to the experimental hypotheses. Across Experiments 1 and 2, 16 different individuals worked as the second experimenter; the most infants any one experimenter tested was 17 (of 84 possible). Hence, even if one of the experimenters had her *own* hypotheses, and unintentionally acted on them, she alone could not be responsible for the pattern of results obtained here. Second, the physical movements of the second experimenter were constrained by the physical make-up of the apparatus. The narrow slit in the back wall of the apparatus, through which the arm moved, allowed for little, if any, vertical movement of the forearm. Third, the first experimenter was trained to detect and record any deviation in procedure during the final phase of the event; all of the infants included in the sample met the designated procedural criteria.

5. The 7.5-month-olds in Experiment 1 were tested prior to the 4.5-month-olds of the same experiment, and prior to the 4-month-olds in Experiment 2. Beginning with the 4.5- and 4-month-olds, a procedure was implemented to determine whether observers could guess to which event, experimental or control, each infant was assigned. The primary observer was asked at the end of the test session whether the infants had seen an event in which the center portion of the platform was visible and empty, or remained occluded by a second screen, when the screen was lowered. In Experiment 1, 14 of the 27 observers reporting (1 observer failed to report) correctly guessed whether the center of the platform was occluded or empty (cumulative binomial, $p > .05$). In Experiment 2, 17 of the 27 observers reporting (1 observer failed to report) correctly guessed whether the platform was occluded or empty (cumulative binomial, $p > .05$).
6. The infants in Experiment 3 were presented with test events in which (a) the object reappeared either immediately or after an appropriate interval (see Section 4.4) and (b) the window was either open or occluded by a second screen. For the 36 infants tested, the primary observer was asked at the end of the test session whether the infant had seen an immediate- or a normal-reappearance test event and whether the window had been open or occluded. The primary observer guessed correctly for 17 of the 36 infants as to the type of test event and for 16 of the 36 infants as to the status of the window, neither performance significantly different from chance (cumulative binomial, $p > .05$). In addition, the primary observer guessed both the event type and the window status correctly for only 9 of the 36 infants, a performance not significantly different from chance (cumulative binomial, $p > .05$).
7. It is possible that it is not the absolute width of the screen that matters but the width of the screen relative to that of the object. In the immediate-reappearance events presented in this paper, the screen was 5 to 6 times the width of the object. In the Burke (1952) experiments, in the conditions in which adults experienced two discrete object motions the screen was 6 to 10 times the width of the object.

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References

Aguiar, A., & Baillargeon, R. (1999). 2.5-month-old infants' reasoning about when objects should and should not be occluded. *Cognitive Psychology*, *39*, 116–157.

Aguiar, A., & Baillargeon, R. (2002). Developments in young infants' reasoning about occluded objects. *Cognitive Psychology, 45*, 267–336.

Arterberry, M. E. (1997). Perception of object properties over time. In C. Rovee-Collier & L. Lispitt (Eds.), *Advances in infancy research* (Vol. 11, pp. 219–268). Norwood, NJ: Ablex.

Arterberry, M. E., Craton, L. G., & Yonas, A. (1993). Infants' sensitivity to motion-carried information for depth and object properties. In C. E. Granrud (Ed.), *Visual perception and cognition in infancy* (pp. 215–234). Hillsdale, NJ: Lawrence Erlbaum Associates.

Baillargeon, R. (1987). Object permanence in 3.5- and 4.5-month-olds infants. *Developmental Psychology, 23*, 655–664.

Baillargeon, R. (1991). Reasoning about the height and location of a hidden object in 4.5- and 6.5-month-old infants. *Cognition, 38*, 13–42.

Baillargeon, R. (1995). A model of physical reasoning in infancy. In C. Rovee-Collier & L. P. Lipsitt (Eds.), *Advances in infancy research* (Vol. 9, pp. 305–371). Norwood, NJ: Ablex.

Baillargeon, R., & DeVos, J. (1991). Object permanence in 3.5- and 4.5-month-old infants: Further evidence. *Child Development, 62*, 1227–1246.

Baillargeon, R., & Graber, M. (1987). Where's the rabbit? 5.5-month-old infants' representation of the height of a hidden object. *Cognitive Development, 2*, 375–392.

Baillargeon, R., Graber, M., DeVos, J., & Black (1990). Why do you infants fail to search for hidden objects? *Cognition, 36*, 225–284.

Bornstein, M. H. (1985). Habituation of attention as a measure of visual information processing in human infants. In G. Gottlieb & N. Krasnegor (Eds.), *Measurement of audition and vision in the first year of postnatal life* (pp. 253–300). Norwood, NJ: Ablex.

Burke, L. (1952). On the tunnel effect. *Quarterly Journal of Experimental Psychology, 4*, 121–138.

Craton, L. G. (1989). *Infants' perception of figure and ground from kinetic stimulus information*. Unpublished doctoral dissertation, University of Minnesota, Minneapolis.

Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston: Houghton Mifflin.

Gibson, E. J., Gibson, J. J., Smith, O. W., & Flock, H. (1959). Motor parallax as a determinant of perceived depth. *Journal of Experimental Psychology, 58*, 40–51.

Granrud, C. E., Yonas, A., Smith, I. M., Arterberry, M. E., Glicksman, M. L., & Sorknes, A. (1984). Infants' sensitivity to accretion and deletion of texture as information for depth at an edge. *Child Development, 55*, 1630–1636.

Hespos, S. (2000, July). *Tracking individual objects across occlusion and containment events in 6.5-month-old infants*. Presented at the international conference on infant studies, Brighton, UK.

Hespos, S., & Rochat, P. (1997). Dynamic mental representation in infancy. *Cognition, 64*, 153–188.

Kaplan, G. (1969). Kinetic disruption of optical texture: The perception of depth at an edge. *Perception and Psychophysics, 6*, 193–198.

Kaufman-Hayoz, R., Kaufman, F., & Stucki, M. (1986). Kinetic contours in infants' visual perception. *Child Development, 57*, 353–358.

Kellman, P. J. (1993). Kinematic foundations of infant perception. In C. E. Granrud (Ed.), *Visual perception and cognition in infancy* (pp. 121–174). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kellman, P. J., & Spelke, E. S. (1983). Perception of partly occluded objects in infancy. *Cognitive Psychology, 15*, 483–524.

Kellman, P. J., Spelke, E. S., & Short, K. R. (1986). Infant perception of object unity from translatory motion in depth and vertical translation. *Cognitive Development, 57*, 72–86.

Leslie, A., Xu, F., Tremoulet, P., & Scholl, B. (1998). Indexing and the object concept: Developing "what" and "where" systems. *Trends in Cognitive Sciences, 2*, 10–18.

Michotte, A., Thines, G., & Crabbe, G. (1991). Amodal completion of perceptual structures. In G. Thines, A. Costall, & G. Butterworth (Eds.), *Michotte's experimental phenomenology of perception*. Hillsdale, NJ: Lawrence Erlbaum Associates (original work published in French in 1964).

Oakes, L. M., & Cohen, L. B. (1995). Infant causal perception. In C. Rovee-Collier & L. Lipsitt (Eds.), *Advances in infancy research* (Vol. 9, pp. 1–54). Norwood, NJ: Ablex.

Putthoff, A., & Wilcox, T. (1997, April). *Young infants' use of discontinuity of speed to reason about object identity*. Presented at the annual meeting of the Southwestern Psychological Association, Fort Worth, TX.

Rochat, P., & Hespos, S. J. (1996). Tracking and anticipation of invisible spatial transformation by 4- to 8-month-old infants. *Cognitive Development*, *11*, 3–17.

Spelke, E. S. (1985). Preferential looking methods as tools for the study of cognition in infancy. In G. Gottlieb & N. Krasnegor (Eds.), *Measurement of audition and vision in the first year of postnatal life* (pp. 323–363). Norwood, NJ: Ablex.

Spelke, E. S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review*, *99*, 605–632.

Spelke, E. S., & Kestenbaum, R. (1986). Les origines du concept d'objet. *Psychologie Francaise*, *31*, 67–72.

Spelke, E. S., Kestenbaum, R., Simons, D. J., & Wein, D. (1995). Spatiotemporal continuity, smoothness of motion and object identity in infancy. *British Journal of Developmental Psychology*, *13*, 113–143.

Tremoulet, P. D., Leslie, A. M., & Hall, G. D. (2001). Infant individuation and identification of objects. *Cognitive Development*, *15*, 499–522.

Van de Walle, G. A., & Spelke, E. S. (1996). Spatiotemporal integration and object perception in infancy: Perceiving unity versus form. *Child Development*, *67*, 2621–2640.

Vicario, G. B., & Kiritani, Y. (1999). Slow-motion tunnel effect: An inquiry into vertical organization of perceptual events. *Gestalt Theory*, *21*, 100–121.

von Hofsten, C. (1997). On the early development of predictive abilities. In C. Dent-Read & P. Zukow-Goldring (Eds.), *Evolving explanations of development* (pp. 163–194). Washington, DC: American Psychological Association.

Wilcox, T. (1999). Object individuation: Infants' use of shape, size, pattern, and color. *Cognition*, *72*, 125–166.

Wilcox, T., & Baillargeon, R. (1998a). Object individuation in infancy: The use of featural information in reasoning about occlusion events. *Cognitive Psychology*, *37*, 97–155.

Wilcox, T., & Baillargeon, R. (1998b). Object Individuation in young infants: Further evidence with an event-monitoring task. *Developmental Science*, *1*, 127–142.

Wilcox, T., & Chapa, C. (2002). Infants' reasoning about opaque and transparent occluders in an individuation task. *Cognition*, *85*, B1–B10.

Wilcox, T., & Schweinle, A. (2002). Object individuation and event mapping: Infants' use of featural information. *Developmental Science*, *5*, 87–105.

Wilcox, T., Nadel, L., & Rosser, R. (1996). Location memory in healthy preterm and full-term infants. *Infant Behavior and Development*, *19*, 309–323.

Wilcox, T., Schweinle, A., Chapa, C. (2003). Object individuation in infancy. In F. Fagan & H. Hayne (Eds.), *Progress in infancy research* (Vol. 3, pp. 193–243).

Wynn, K. (1992). Addition and subtraction by human infants. *Nature*, *358*, 749–750.

Xu, F., & Carey, S. (1996). Infants' metaphysics: The case of numerical identity. *Cognitive Psychology*, *30*, 111–153.