ACADEMIC PRESS

Cognitive Psychology 45 (2002) 267–336

Cognitive Psychology

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Developments in young infants' reasoning about occluded objects☆

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Accepted 19 October 2001

Abstract

Eight experiments were conducted to examine 3- and 3.5-month-old infants' responses to occlusion events. The results revealed two developments, one in infants' knowledge of when objects should and should not be occluded and the other in infants' ability to posit additional objects to make sense of events that would otherwise violate their occlusion knowledge. The first development is that, beginning at about 3 months of age, infants expect an object to become temporarily visible when passing behind an occluder with an opening extending from its lower edge. The second development is that, beginning at about 3.5 months of age, infants generate a two-object explanation when shown a violation in which an object *fails* to become visible when passing behind an occluder with an opening in its lower edge. Unless given

☆ This research was supported by grants to the first author from the Natural Sciences and Engineering Research Council of Canada, The University of Waterloo, and CAPES-Brasilia/Brasil (BEX-2688); and by a grant to the second author from the National Institute of Child Health and Human Development (HD-21104). We thank Susan Carey, Dov Cohen, Cynthia Fisher, Kristine Onishi, Philippe Rochat, and Jason Sullivan for many helpful comments and suggestions; Yuyan Luo and Karen Menard for their help with the statistical analyses; and Laura Brueckner, Deepa Block, Beth Cullum, Laura Glaser, Susan Hespos, Gavin Huntley-Fenner, Lisa Kaufman, Laura Kotovsky, Melsie Minna, Helen Raschke, Teresa Wilcox, and the undergraduate assistants in the Infant Cognition Laboratory at the University of Illinois for their help with the data collection. We also thank the parents who kindly agreed to have their infants participate in the research.

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PII: S0010-0285(02)00005-1

information contradicting such an explanation, infants infer that two identical objects are involved in the event, one traveling to the left and one to the right of the opening. These and related findings provide the basis for a model of young infants' responses to occlusion events; alternative models are also discussed.

1. Introduction

As adults, we often observe situations in which objects become occluded by nearer objects. For example, we might see a child hide behind a couch, a ball roll behind a toy chest, or a spoon fall behind a pot. Our representations of these occlusion situations typically include both the objects that remain visible—the couch, the toy chest, the pot—and the objects that do not—the child, the ball, the spoon. Are infants, like adults, able to represent occluded objects? Piaget (1954) was the first investigator to examine this question. He concluded that it is not until infants are about 8 months of age that they begin to represent the continued existence of occluded objects. This conclusion was based primarily on data from manual search tasks. Piaget found that young infants typically do not search for objects they have observed being hidden: If a toy is covered with a cloth, for example, infants ages 5–7 months make no attempt to lift the cloth and grasp the toy, even though they are usually capable of performing each of these actions.

For the next several decades, researchers generally accepted Piaget's (1954) conclusion that young infants' event representations include only those objects they can directly perceive (for reviews of this early research, see Bremner, 1985; Gratch, 1976; Harris, 1987; Schubert, 1983). This state of affairs began to change during the 1980s, however, when evidence obtained with novel, more sensitive tasks contradicted Piaget's long-standing conclusion (e.g., Baillargeon, 1986, 1987; Baillargeon & Graber, 1987; Baillargeon, Spelke, & Wasserman, 1985; Hood & Willatts, 1986; Spelke & Kestenbaum, 1986). Today, there is consistent evidence from multiple laboratories that infants ages 2.5 months and older believe that (1) a stationary object continues to exist and retains its location when occluded and (2) a moving object continues to exist and pursues a continuous path when occluded (e.g., Aguiar & Baillargeon, 1999, 2000; Baillargeon, 1991; Baillargeon & DeVos, 1991; Baillargeon, Graber, DeVos, & Black, 1990; Goubet & Clifton, 1998; Hespos & Baillargeon, 2001a,b; Hespos & Rochat, 1997; Hofstadter & Reznick, 1996; Koechlin, Dehaene, & Mehler, 1998; Lécuyer, 1993; Newcombe, Huttenlocher, & Learmonth, 1999; Rochat & Hespos, 1996; Simon, Hespos, & Rochat, 1995; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Wilcox, 1999; Wilcox & Baillargeon, 1998b; Wilcox, Nadel, & Rosser, 1996; Wynn, 1992).

Such evidence does not mean, of course, that infants as young as 2.5 months of age know all there is to know about occlusion events. Indeed, recent experiments point to two distinct facets of young infants' reasoning about occluded objects that undergo clear developmental change (Aguiar & Baillargeon, 1999; Baillargeon & DeVos, 1991; Spelke & Kestenbaum, 1986; Spelke, Kestenbaum, Simons, & Wein, 1995a). One facet concerns infants' knowledge of the conditions under which objects should and should not be occluded. The other facet involves infants' ability to posit the existence of an additional occluded object to make sense of an event that would otherwise violate their occlusion knowledge. We next review the results of these experiments, which provided the basis for the present research.

1.1. Predicting when objects should and should not be occluded

There are now several published reports that infants ages 2.5–3.5 months believe that an object continues to exist *after* it becomes occluded (e.g., Aguiar & Baillargeon, 1999; Baillargeon, 1987; Baillargeon & DeVos, 1991; Hespos & Baillargeon, 2001b; Spelke et al., 1992; Wilcox et al., 1996; we return to the possible origins of this belief under Section 9). At the same time, however, there is also evidence that these young infants are rather poor at predicting *when* an object should be occluded. This evidence comes from two series of experiments, one involving 2.5-months-olds (Aguiar & Baillargeon, 1999) and the other 3- and 3.5-month-olds (Baillargeon & DeVos, 1991). Both series of experiments examined infants' ability to predict whether an object should remain continuously hidden or become temporarily visible when passing behind a screen with an opening in its midsection. Both series of experiments also made use of the violation-of-expectation method (e.g., Baillargeon, 1995, 1998; Spelke, 1985). In a typical experiment conducted with this method, infants see two test events: One is consistent with the belief or expectation being examined in the experiment (expected event), and the other violates this expectation (unexpected event). Prior to seeing the test events, infants may see habituation events designed to familiarize them with various aspects of the test situation.[1] With appropriate controls, reliably longer looking at the unexpected than at the expected event provides evidence that infants (1) possess the expectation under

[1] It is often assumed that habituation trials are an essential component of the violation-of-expectation method, but this assumption is incorrect. In this method (unlike the habituation–dishabituation method; see Baillargeon, 1998, 2000), habituation trials are typically included to help infants orient to the experimental situation so that they (1) focus on the key aspects of the test events and (2) respond to these events differentially rather than remain at ceiling throughout the test trials. In some of our recent experiments with infants aged 3.5 months and older, habituation trials were reduced to a few familiarization trials or eliminated altogether (e.g., Baillargeon & Brueckner, 2000; Baillargeon et al., 1990; Needham & Baillargeon, 1993).

examination, (2) detect the violation in the unexpected event, and (3) are surprised by this violation. Throughout this article, we use the term "surprise" as a shorthand descriptor to denote a state of heightened attention or interest induced by an expectation violation. We make no claims here about the presence or absence of emotional components in this response.[2]

Experiments with 2.5-month-old infants. In a recent series of experiments (Aguiar & Baillargeon, 1999), 2.5-month-old infants were habituated to a toy mouse ("Minnie Mouse") that moved back and forth along a track whose center was hidden by a screen (see Fig. 1). The mouse disappeared at one edge of the screen and, after an appropriate interval, reappeared at the other edge. Following habituation, the infants saw two test events. In one (high-window event), a window was created in the screen's upper half; the mouse was shorter than the bottom of the window and so did not become visible when passing behind the screen. In the other event (two-screen event), the entire midsection of the screen was removed, yielding two separate screens. In this event, the mouse should have appeared in the gap between the screens, but it did not in fact do so; the mouse disappeared behind one screen and reappeared from behind the other screen *without* appearing in the gap between them.

The infants looked reliably longer at the two-screen than at the high-window test event. This result suggested that, when shown the two-screen event, the infants (1) believed that the mouse continued to exist when behind one of the screens, (2) realized that the mouse could not disappear behind one screen and reappear from behind the other screen without traveling the distance between them, and (3) expected the mouse to appear between the screens and were surprised when it failed to do so. This interpretation was supported by the results of a control experiment identical to that just described with one exception: The screen or screens were lowered at the start of each trial to reveal two identical mice. The infants in this control experiment tended to look equally at the two-screen and high-window test events. This negative result suggested that the infants were able to use the information provided at the start of each trial to make sense of the two-screen event: That is, they realized that no mouse appeared in the gap between the screens because one mouse traveled to the left and one to the right of the gap.

[2] Although no systematic evidence has yet been gathered involving facial or behavioral correlates of surprise in violation-of-expectation experiments, we have occasionally observed such reactions in our laboratory, particularly in older infants, and for this reason we suspect that there are at times emotional overtones to infants' reactions to unexpected events, just as is the case with adults. Until formal evidence is at hand, however, the term surprise should be understood to refer simply to the cognitive state of increased interest infants experience when confronted by events that violate their physical knowledge.

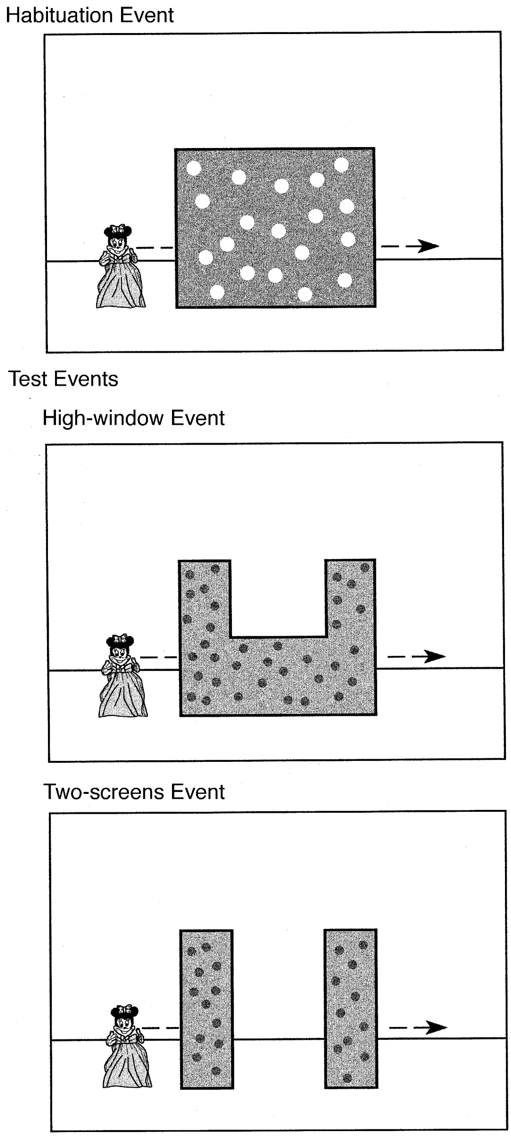

Fig. 1. Schematic drawing of the habituation and test events in Aguiar and Baillargeon (1999).

In a subsequent experiment (Aguiar & Baillargeon, 1999), 2.5-month-old infants saw test events identical to those just described, except that the two-screen event was modified (see Fig. 2): Only the lower portion of the screen's midsection was removed, creating a low window (low-window event).

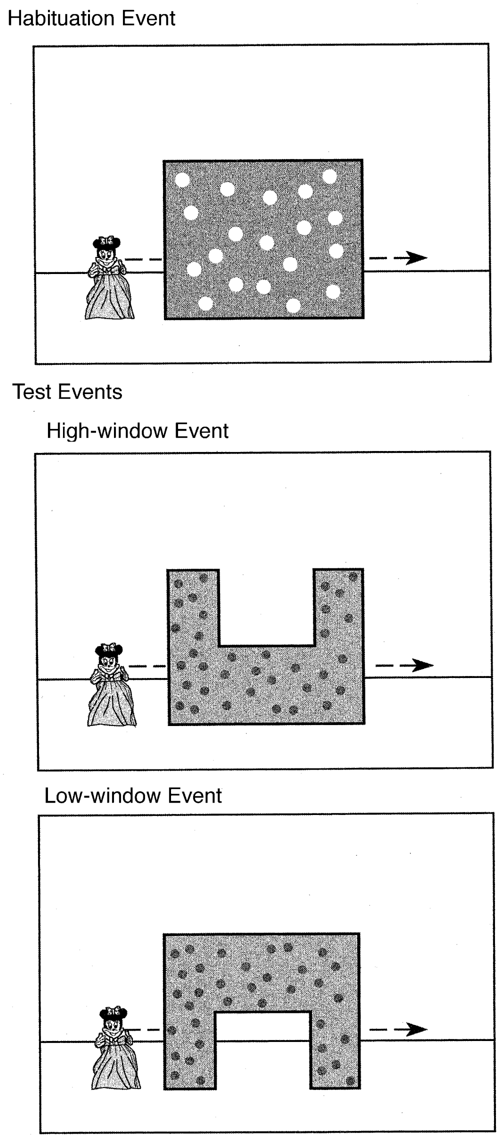

Fig. 2. Schematic drawing of the habituation and test events in Aguiar and Baillargeon (1999) and in Experiment 1.

Because the mouse was shorter than the top of the window, it should have become fully visible—as in the two-screen event—when passing behind the screen. In this experiment, however, the infants tended to look equally at the low- and high-window test events.

Our interpretation of the preceding results—all of which were confirmed in additional experiments conducted with slightly different versions of the events (Aguiar & Baillargeon, 1999)—was that 2.5-month-old infants' knowledge of the conditions under which objects should and should not be occluded is still very limited. Specifically, infants possess only an initial concept centered on a *behind/not-behind* distinction: They expect objects to be hidden when behind occluders and to be visible otherwise. At this stage, infants have not yet learned to take into account the presence and location of openings in occluders when judging whether objects should be hidden or visible: Objects are expected to be hidden as long as they are *behind* occluders, whether or not these have openings. Thus, the infants in the experiments just described did not expect the mouse to become visible when passing behind the screen in the low- or high-window test event because in each case the screen constituted a single occluder and the infants' initial concept suggested that the mouse would be hidden when behind this occluder. In the two-screen test event, in contrast, the infants expected the mouse to become visible in the gap between the screens because at that point the mouse did not lie behind any occluder.

Experiments with 3- and 3.5-month-old infants. In another series of experiments (Baillargeon & DeVos, 1991), 3- and 3.5-month-old infants were habituated to a toy carrot that moved back and forth along a track whose center was hidden by a screen (see Fig. 3). On alternate trials, the infants saw a tall and a short carrot slide along the track. Following habituation, the midsection of the screen's upper half was removed to create a high window, and the infants saw two test events. In one (short-carrot event), the short carrot moved along the track; this carrot was shorter than the bottom of the window and so did not become visible when passing behind the screen. In the other event (tall-carrot event), the tall carrot moved along the track; this carrot was taller than the bottom of the window and hence should have become visible when passing behind the screen, but it in fact never appeared in the window.

Different results were obtained with the 3- and 3.5-month-old infants. The older infants tended to look equally at the tall- and short-carrot habituation events, but looked reliably longer at the tall- than at the short-carrot test event. These results suggested that the infants (1) believed that each carrot continued to exist when behind the screen, (2) realized that each carrot could not disappear at one edge of the screen and reappear at the other edge without traveling the distance between them, (3) recognized that the height of each carrot relative to that of the window determined whether the carrot should appear in the window, and hence (4) expected the tall carrot to appear in the window and were surprised when it failed to do so. This interpretation was supported by the results of a control experiment identical to the initial experiment with one exception: At the start of the testing session, the

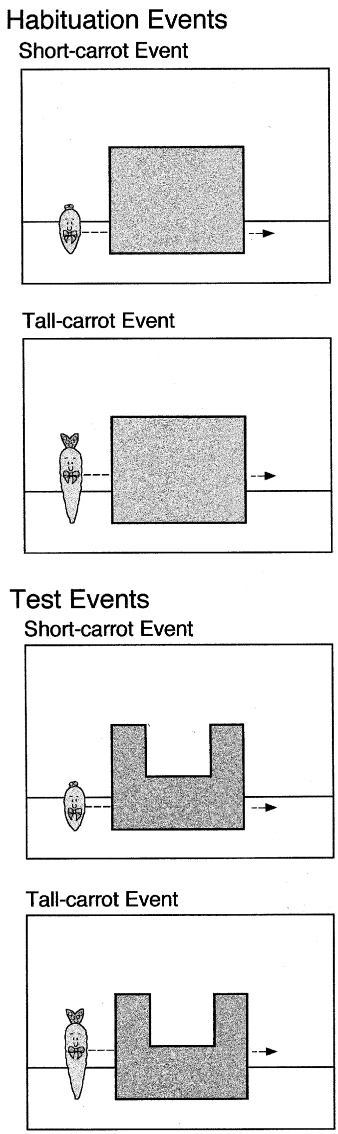

Fig. 3. Schematic drawing of the habituation and test events in Baillargeon and DeVos (1991).

infants received two pretest trials in which they saw two identical carrots standing motionless on either side of the habituation screen; the infants saw two tall carrots in one trial and two short carrots in the other (Baillargeon & DeVos, 1991). The infants in this control experiment tended to look equally at the tall- and short-carrot test events, suggesting that they were able to use the information provided in the pretest trials to make sense of the tall-carrot event.

The 3-month-old infants in the initial experiment, unlike the 3.5-month-old infants, tended to look equally at the tall- and short-carrot test events. This negative result suggested that the younger infants were not surprised when the tall carrot failed to appear in the window.

Our interpretation of the preceding results was that, by 3.5 months of age, infants have progressed beyond their initial concept of when objects should and should not be occluded: They now consider height information when reasoning about occlusion events. Thus, when watching an object pass behind a screen with a high window, infants expect the object to remain hidden if it is shorter but not taller than the bottom of the window (for similar results with older infants, see Baillargeon & Graber, 1987; Hespos & Baillargeon, 2001a). At 3 months of age, however, infants have not yet identified height as an important occlusion variable; when watching an object pass behind a screen with a high window, infants expect the object to remain hidden irrespective of whether it is shorter or taller than the bottom of the window.

In the present research, we asked whether 3-month-old infants could judge correctly whether an object should become visible when passing behind a screen with a *low* as opposed to a high window. In such a situation, it is not necessary to encode and compare the relative heights of the object and window to arrive at a correct prediction. From simply knowing that an object is approaching an occluder with an opening extending from its lower edge, one can predict that the object will appear in the opening (as long, of course, as the object and occluder rest on the same horizontal plane; a suspended object might pass above the window). It seemed possible that 3-month-old infants might be able to reason successfully about openings extending from the lower edges of occluders and still fail at reasoning about openings extending from the upper edges of occluders.

In Experiment 1, 3- and 3.5-month-old infants were tested with the same low-window mouse task we had used with 2.5-month-old infants (see Fig. 2; Aguiar & Baillargeon, 1999). As before, the infants were habituated to the mouse moving back and forth behind the screen and then were shown the high- and low-window test events. Given the results presented above, we expected the 3.5-month-old infants to readily detect the violation in the low-window event. The question of interest was whether the 3-month-old infants would also be successful. Negative results would suggest that 3-month-old infants are essentially similar to 2.5-month-old infants in their reasoning about occlusion events and expect any object to remain hidden when passing behind any occluder. On the other hand, positive results would indicate that, by 3 months of age, infants have begun to progress beyond their initial concept of when objects should be occluded: They now expect objects to become visible when passing behind occluders with openings extending from their lower edges.

1.2. Positing the existence of additional occluded objects

Spelke and her colleagues (Spelke & Kestenbaum, 1986; Spelke et al., 1995a) have reported evidence that young infants are not only able to represent objects that become occluded: They are also able to *posit* the existence of additional occluded objects to make sense of events that would otherwise violate their expectations as to when objects should and should not be occluded.

In one experiment (Spelke & Kestenbaum, 1986), 4-month-old infants were habituated to a suspended cylinder that slid back and forth along a track; at the center of the track were two screens separated by a gap. The cylinder disappeared behind one screen and reappeared from behind the other screen without ever appearing in the gap between the screens. Following habituation, the screens were removed, and the infants saw two test events. In one (one-cylinder event), a single cylinder traveled the entire length of the track. In the other event (two-cylinder event), two identical cylinders moved sequentially along the track; the left cylinder had the same trajectory as the cylinder shown to the left of the screens in the habituation event, and the right cylinder had the same trajectory as the cylinder shown to the right of the screens.

The infants looked reliably longer at the one- than at the two-cylinder test event. Further results (Spelke et al., 1995a) established that the infants' preference for the one-cylinder event reliably exceeded that of control infants who were shown only the test events. Spelke (1990) and Spelke and Kestenbaum (1986) took these findings to suggest that the infants in the experimental condition (1) inferred, upon observing that no cylinder appeared between the screens in the habituation event, that two distinct cylinders were involved in the event, and therefore (2) expected to see two cylinders when the screens were removed and were surprised in the one-cylinder event when this expectation was violated. Thus, according to this interpretation, infants as young as 4 months of age can not only represent the existence of objects that become occluded, but can also infer the existence of additional occluded objects. Such a finding is important because it makes clear that young infants' representations of occlusion events are not mere copies of the events, but complex constructions that reflect both their physical knowledge and problem solving processes.

Comparison of the results of Spelke and Kestenbaum (1986) with those of the two-screen mouse experiment described above (see Fig. 1; Aguiar & Baillargeon, 1999) brings to light another developmental change in young infants' reasoning about occlusion events. Recall that the 2.5-month-old infants in that experiment responded with prolonged looking when the mouse failed to appear in the gap between the two screens. This result suggests that the infants did *not* posit the existence of a second, identical mouse behind the screens. Had the infants generated such an explanation, they would most likely have produced shorter looking times, similar to those of the infants in the control experiment who were shown two mice at the start of each trial.

At what age between 2.5 and 4 months of age do infants begin to posit additional occluded objects to make sense of events that would otherwise violate their occlusion knowledge? We speculated that the present research might help shed light on this question. Evidence that the 3-month-old infants in Experiment 1 looked reliably longer at the low- than at the high-window test event, but that the 3.5-month-old infants did *not*, would suggest that these older infants were able to produce a two-mouse explanation for the low-window event: That is, they realized that no mouse appeared in the window because no mouse traveled the entire distance behind the screen; instead, two identical mice traveled on opposite sides of the window.[3]

We were aware that additional evidence would be needed to support this interpretation. Nevertheless, we reasoned that such an interpretation, if valid, would not only help pinpoint the age at which infants can first infer the existence of additional occluded objects, but would also provide converging evidence for Spelke's conclusion that young infants are indeed capable of positing occluded objects (Spelke & Kestenbaum, 1986; Spelke et al., 1995a). Such evidence is important because there is a potential ambiguity in the approach adopted by Spelke and her colleagues. This ambiguity is suggested by the results of the control mouse and control carrot experiments described earlier (Aguiar & Baillargeon, 1999; Baillargeon & DeVos, 1991). The 2.5-month-old infants who saw two mice at the start of each trial readily made use of this hint to generate an explanation for the two-screen test event. Similarly, the 3.5-month-old infants who saw two tall carrots at the start of the experiment were able to use this (subtler) hint to make sense of the tall-carrot test event. Such results raise concerns as to *when* the 4-month-old infants tested by Spelke and Kestenbaum might have become aware that two cylinders were involved in the habituation event: (1) during the habituation event itself, upon observing that no cylinder appeared between the two screens, or (2) during the two-cylinder test event, upon seeing the two cylinders and realizing that they provided an explanation for the habituation event. In the latter case, one would not be justified in claiming that young infants can posit the existence of an occluded object; one could

[3] We focused on the 3.5-month-old infants in our predictions because we realized that negative results with the 3-month-old infants would be difficult to interpret: Such results could reflect either (1) their inability to detect the violation in the low-window test event, due to their limited knowledge of occlusion events, or (2) their ability to generate an explanation for the event.

conclude only that young infants can take advantage of a hint to make sense of a violation event even when they receive the hint *after* the event.[4]

How likely were the 3.5-month-old infants in Experiment 1 to infer that two identical mice were used to produce the low-window test event? One reason for being skeptical about such an outcome was that the 3.5-month-old infants in the carrot experiment were *not* able to generate a two-carrot explanation for the tall-carrot test event; it was only when this explanation was suggested to them that infants' surprise at the event receded (Baillargeon & DeVos, 1991). Furthermore, even 5.5-month-old infants failed to generate a two-object explanation when tested with a task similar to the carrot task (Baillargeon & Graber, 1987).

There was, however, a crucial difference between the carrot task (Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987), on the one hand, and the tasks used in Experiment 1 and in Spelke and Kestenbaum (1986), on the other. The infants in the latter two tasks faced a much more flagrant occlusion violation than did the infants in the carrot task. In these tasks, the *entire* mouse or cylinder failed to become visible as expected; in the carrot task, in contrast, only *the top portion* of the tall carrot failed to become visible. It could be that the infants in the carrot task (1) assumed that the tall carrot traveled the distance behind the screen but then (2) were puzzled as to why the top of the carrot did not appear in the window. In the tasks used in Experiment 1 and in Spelke and Kestenbaum (1986), the infants could *not* assume that the mouse traveled from one end of the screen to the other or that the cylinder traveled from one screen to the other; such tasks could thus be more conducive to infants' production of two-object explanations.

Evidence for this possibility came from a preliminary experiment with 5.5-month-old infants (reported in Baillargeon, 1994b). The infants saw habituation and test events similar to those in Experiment 1, except that toy

[4] Another reason to seek converging evidence for the conclusion that young infants can infer the existence of occluded objects had to do with the mixed results of additional experiments by Spelke and her collaborators. Spelke and Kestenbaum (1986) were concerned that the infants in their initial experiment might have preferred the one-cylinder test event, not because they were surprised to see a single cylinder, but because they were interested to see the cylinder move through the central portion of the track (recall that no cylinder appeared between the two screens during the habituation trials). To examine this interpretation, Spelke and Kestenbaum tested an additional group of 4-month-old infants with the same habituation and test events as before with one exception: In the one-cylinder event, the cylinder followed either the left or the right trajectory shown in the two-cylinder test event. The results indicated that the infants again looked reliably longer at the one- than at the two-cylinder event. However, a replication conducted with a larger sample (Spelke et al., 1995a) failed to confirm this finding; the infants did not display a preference for the one- over the two-cylinder event, and their responses did not differ reliably from those of control infants who were shown only the test events. In light of these negative data, it is difficult to draw firm conclusions about the infants' interpretations of the events (Spelke et al., 1995a).

rabbits were used instead of toy mice. The infants tended to look equally at the low- and high-window test events. This negative finding contrasted with the positive results obtained in the carrot experiments (Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987) and supported Spelke's conclusion (Spelke & Kestenbaum, 1986; Spelke et al., 1995a) that young infants are able, under some conditions at least, to posit the existence of occluded objects.

Experiment 1 thus examined whether 3.5-month-old infants (1) would show a reliable preference for the low- over the high-window test event, suggesting that they were surprised by, and could not spontaneously generate an explanation for, the mouse's failure to appear in the low window, or (2), like the 5.5-month-olds in the preliminary experiment just described (Baillargeon, 1994b), would show no preference for the low-window event, suggesting that they readily inferred that two identical mice were involved in the event.

2. Experiment 1

In Experiment 1, 3- and 3.5-month-old infants were tested using the low-window mouse task described earlier (Aguiar & Baillargeon, 1999; see Fig. 2). The infants were first habituated to a toy mouse moving back and forth behind a screen. Next, the infants saw test events similar to the habituation event, except that the screen had a window in its upper (high-window event) or lower (low-window event) midsection. The mouse's visible trajectory was exactly the same in all of the habituation and test events.

2.1. Method

2.1.1. Participants

Participants were 20 healthy term infants. There were 10 3-month-old infants, 5 male and 5 female, ranging in age from 91 to 100 days ($M = 93.8$ days), and 10 3.5-month-old infants, 5 male and 5 female, ranging in age from 101 to 127 days ($M = 109.2$ days). An additional 16 infants were tested but eliminated;[5] they failed to complete four valid test trials, 9 because of fussiness, 2 because of drowsiness, and 5 because they looked for the

[5] The large proportion of eliminated subjects in this and in the following experiments is not uncommon with very young infants (e.g., Aguiar & Baillargeon, 1999; Baillargeon & DeVos, 1991; Canfield & Haith, 1991; Haith & McCarty, 1990). Our typical response to this high attrition rate—which we again followed here—has been to use relatively small samples of 10–12 infants in each experiment, but to conduct multiple experiments to both explore the phenomenon further and confirm main findings (e.g., Aguiar & Baillargeon, 1999).

maximum amount of time allowed (90 s) on three or more test trials. The infants' names in this and in the following experiments 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 similar to that in Aguiar and Baillargeon (1999) and consisted of a wooden display box 124 cm high, 102 cm wide, and 33.5 cm deep that was positioned 76 cm above the room floor. The infant faced an opening 56 cm high and 95 cm wide in the front of the apparatus. The side walls of the apparatus were painted white and the floor was covered with a brightly lined contact paper. The back wall was constructed of gray foam-core board and had an opening 5 cm high and 94 cm wide centered along its lower edge; this opening was filled with a gray fringe.

Three cardboard screens were used in the experiment, one in the habituation event, one in the high-window test event, and one in the low-window test event. Each screen was centered between the apparatus's side walls, 10 cm in front of the back wall. The screens were 30 cm high and 38 cm wide and were supported at the back by a metal frame. Each test screen had a window 15 cm high and 18 cm wide; this window was centered in either the upper half (high-window event) or lower half (low-window event) of the screen. The habituation screen was dark purple with large yellow dots, and its edges were outlined with black tape. The test screens were bright green with small red dots, and their edges were outlined with red tape.

Two identical plastic toy mice (Minnie Mouse dolls) were used in the habituation and test events. The mice were 14 cm high, 5 cm thick, and 7 cm wide (at their widest points), and they stood 2.5 cm from the apparatus's back wall. Each mouse was dressed in a red cotton skirt that fell past her feet. The mice were mounted on hidden carriers 0.5 cm above the apparatus floor so that, as the mice moved, only their skirts brushed noiselessly against the floor.

Each mouse carrier consisted of a thin, L-shaped metal rod. The vertical portion of the rod stood in front of the apparatus' back wall; the top of the rod was bent and was inserted in the back of the mouse's head. The horizontal portion of the rod lay 3.75 cm above the apparatus floor and protruded through the opening in the back wall; behind the wall, the rod was attached to a small Plexiglas base. Each carrier base rested against a Plexiglas rail on a Plexiglas track that ran parallel to the back wall. To ensure that the carrier bases slid smoothly and silently along the rail and track, the front and bottom surfaces of each carrier base were covered with felt.

An experimenter moved one carrier base along the left half of the track and the other carrier base along the right half of the track. To help the experimenter slide the carriers at an even pace, a row of equally spaced marks was placed above the opening in the back wall of the apparatus. In addition, the experimenter listened to a metronome that beat once per second.

Two call bells were used to draw the infants' attention to the left and right ends of the mice's trajectory across the apparatus. One bell stood behind each end of the track and was rung (by depressing the chime at the top of the bell) each time the carrier paused in front of it.

The infants were tested in a brightly lit room. Three 20-W fluorescent light bulbs attached to the front and back walls of the apparatus provided additional light. Two wooden frames, each 182.5 cm high and 71 cm wide and covered with blue cloth, stood at an angle on either side of the apparatus; these frames served to isolate the infants from the experimental room. At the end of each trial, a curtain consisting of a muslin-covered frame 60 cm high and 101 cm wide was lowered in front of the apparatus.

2.1.3. Events

In the following text, the numbers in parentheses indicate the number of seconds taken to perform the actions described. The events are described from the infant's perspective.

2.1.3.1. Habituation event. In the habituation event, the windowless purple screen stood in front of the back wall. At the start of the trial, the mouse on the left carrier stood in the left corner of the apparatus, 2.5 cm from the side wall; the mouse on the right carrier stood behind the screen's right edge and was not visible to the infant. The experimenter rang the bell behind the left carrier once (1 s) and then slid the left carrier at the speed of about 15 cm/s until the mouse had moved 30 cm (2 s) and stood behind the left edge of the screen, hidden from the infant. After a 2-s pause, the experimenter slid the right carrier at the same speed of about 15 cm/s until the mouse had moved 30 cm (2 s) and stood in the right corner of the apparatus, 2.5 cm from the side wall. The entire process was then repeated in reverse, from right to left. The experimenter rang the bell behind the right carrier once (1 s) and then slid the mouse to its starting position behind the screen's right edge (2 s). After a 2-s pause, the left mouse was moved from behind the screen's left edge back to its initial position in the left corner of the apparatus (2 s). Each event cycle thus lasted approximately 14 s. Cycles were repeated until the computer signaled that the trial had ended (see below). When this occurred, a second experimenter lowered the curtain in front of the apparatus.

2.1.3.2. Low- and high-window test events. The high- and low-window test events were identical to the habituation event, except that the windowless purple screen was replaced by the green screen with the high window in the high-window test event and by the green screen with the low window in the low-window test event.

2.1.3.3. Adults' responses to the low- and high-window test events. How would adults interpret the low- and high-window test events? To find out, 24 college students, 8 male and 16 female ($M = 18.5$ years), were tested with these events. Half of the participants saw the low- and half the high-window event. The participants saw one cycle of the event (14 s) and then were asked (1) to rate their level of surprise at the event on a scale from 1 (*not surprised*) to 6 (*very surprised*), (2) to describe the event, and (3) to explain how it was produced.

The surprise ratings of the adults who saw the low- and high-window test events were compared by means of a one-way analysis of variance (ANOVA) and were found to be significantly different, $F(1,22) = 87.35$, $p < .0001$. The adults who saw the low-window event were reliably more surprised ($M = 5.3$, $SD = 0.8$) than were those who saw the high-window event ($M = 1.5$, $SD = 1.2$). Examination of the participants' event descriptions suggested that the low-window adults expected the mouse to appear in the window and were surprised when it failed to do so (e.g., "It seemed as though Minnie would be visible behind the window, but she wasn't—I was surprised by this!"). The high-window adults did not expect the mouse to appear in the window and hence were not surprised when it did not (e.g., "Minnie went from left to right and then back; she passed behind the screen, she disappeared temporarily. I was not surprised because Minnie was too short to be seen above the screen"). Finally, when asked how the event was produced, 8 of the 12 low-window adults guessed that two identical mice traveled on the opposite sides of the window (e.g., "Most likely there were two Minnies"); the other 4 participants produced more complex explanations in which a fake background hid the mouse when passing behind the window ($n = 2$) or the mouse was lifted up and around the window ($n = 2$). In the high-window condition, only 1 participant suggested that two mice might be involved in the event; the other 11 participants all believed that a single mouse was moved back and forth across the apparatus (e.g., "Minnie was attached to a stick and moved across the stage").

2.1.4. Procedure

During the experiment, the infant sat on his or her parent's lap in front of the apparatus, facing the screen. The infant's head was approximately 60 cm from the screen and 70 cm from the back wall of the apparatus. Parents were asked not to interact with their infant during the experiment and to close their eyes during the test trials.

The infant's looking behavior was monitored by two observers who viewed the infant through peepholes in the cloth-covered frames on either side of the apparatus. The observers could not see the events from their viewpoints and they did not know the order in which the test events were presented. Each observer held a button box linked to a computer and depressed the button when the infant attended to the events. The looking times recorded by the primary observer were used to determine when a trial had ended (see below). At the end of each trial, the observers rated on a coding sheet (1) the infant's state (i.e., whether the infant was drowsy, quiet and alert, active, fussy, or crying during the trial), (2) the infant's tracking behavior (i.e., whether the infant looked at least once to the left, center, and right portions of the mouse's path during the trial), and (3) the visibility of the infant's looking behavior (i.e., how easily they could determine whether the infant was attending to the event during the trial).

Each infant was tested using a two-phase procedure consisting of a habituation and a test phase. During the *habituation* phase, the infant saw the habituation event described above on successive trials. Each trial ended when the infant either (1) looked away from the event for 2 consecutive seconds after having looked at it for at least 7 cumulative seconds or (2) looked at the event for 90 consecutive seconds without looking away for 2 consecutive seconds. Habituation trials continued until the infant either (1) satisfied a habituation criterion of a 50% or greater decrease in looking time on 3 consecutive trials, relative to the infant's looking time on the first 3 trials, or (2) completed 9 habituation trials. Therefore, the minimum number of habituation trials an infant could receive was 6, and the maximum number was 9. Of the 20 infants in the experiment, 8 (4 3- and 4 3.5-month-old infants) failed to satisfy the habituation criterion within 9 trials; the remaining 12 infants took an average of 7.0 trials to reach the criterion. The infants in the two age groups did not differ significantly in (1) the number of habituation trials they received, $F(1,18) = 0.12$ (3 months: $M = 7.9$, $SD = 1.4$; 3.5 months: $M = 7.7$, $SD = 1.3$), (2) their mean looking times during the first 6 habituation trials, $F(1,18) = 0.67$ (3 months: $M = 62.5$, $SD = 22.5$; 3.5 months: $M = 54.6$, $SD = 21.0$), or (3) their mean looking times during the last 6 habituation trials, $F(1,18) = 1.21$, $p > .05$ (3 months: $M = 56.7$, $SD = 18.1$; 3.5 months: $M = 47.4$, $SD = 19.6$).

During the *test* phase, the infants saw the low- and high-window test events described above on alternate trials until they completed two pairs of test trials. Half of the infants in each age group saw the low-window event first, and half saw the high-window event first. The criteria used to determine the end of each test trial were the same as for the habituation trials with one exception: The minimum value for the infants' looking time at each test event was increased from 7 to 9 s. Pilot data suggested that increasing the minimum looking time to 9 s gave the infants greater opportunity to notice the mouse's reappearance to the right of the screen.

Interobserver agreement during the test trials was measured for all of the infants, except for one trial of one infant: Only one observer was present during this trial. 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. Agreement was calculated for each trial on the basis of the number of intervals in which the computer registered agreement out of the total number of intervals in the trial. Agreement averaged 93.8% per trial per infant.

In addition to measuring interobserver agreement throughout each test trial, we also examined how well the observers agreed on the ending of the test trials. In the experiment, data were available from two observers for 79 test trials (19 infants $\times$ 4 test trials + 1 infant $\times$ 3 test trials). Based on the primary observer's responses, 19 of the trials ended because the infant looked at the event for the maximum amount of time allowed, 90 s, and 60 trials ended because the infant looked away from the event for 2 consecutive seconds. For each of the 90-s trials, the computer calculated the looking time registered by the secondary observer; the average looking time obtained across trials was 89.0 s. For each trial that ended with a 2-s look away, the computer inspected the 20 100-ms intervals corresponding to these 2 s to ascertain (1) whether the secondary observer agreed that the infant was looking away from the event in the final interval and, if yes, (2) for how many consecutive intervals prior to and including the final interval the secondary observer agreed that the infant was looking away. The secondary observer agreed that the infant was looking away during the final interval on 54 of the 60 trials; the average look away recorded by the secondary observer at the end of these trials was 1.8 s. The 6 trials with a disagreement in the final interval were retained in the analyses because on each trial the primary observer (who was typically the more experienced observer) reported high or medium visibility for the infant's looking behavior; infants were eliminated if they had test trials with a final-interval disagreement and the primary observer reported only low visibility on those trials.

Preliminary analyses of the infants' looking times during the test trials revealed no significant interaction involving sex and event, F's < 0.32; the data were therefore collapsed across sex in subsequent analyses.

2.2. Results

Fig. 4 shows the mean looking times of the 3- and 3.5-month-old infants in Experiment 1 at the test events. It can be seen that the younger infants looked longer at the low- than at the high-window event, but that the older infants did not.

The infants' looking times at the test events were averaged and compared by means of a $2 \times 2 \times 2$ ANOVA, with age (3 or 3.5 months) and order (low- or high-window event first) as between-subjects factors and with event (low- or high-window) as a within-subject factor. The analysis revealed a significant main effect of event, $F(1,16) = 7.90$, $p < .025$, and a significant age $\times$ event interaction, $F(1,16) = 6.70$, $p < .025$. Planned comparisons confirmed that the 3-month-old infants looked reliably longer at the low- ($M = 59.2$, $SD = 19.1$) than at the high-window event ($M = 37.1$, $SD = 18.7$), $F(1,16) = 14.57$, $p < .0025$, but that the 3.5-month-old infants

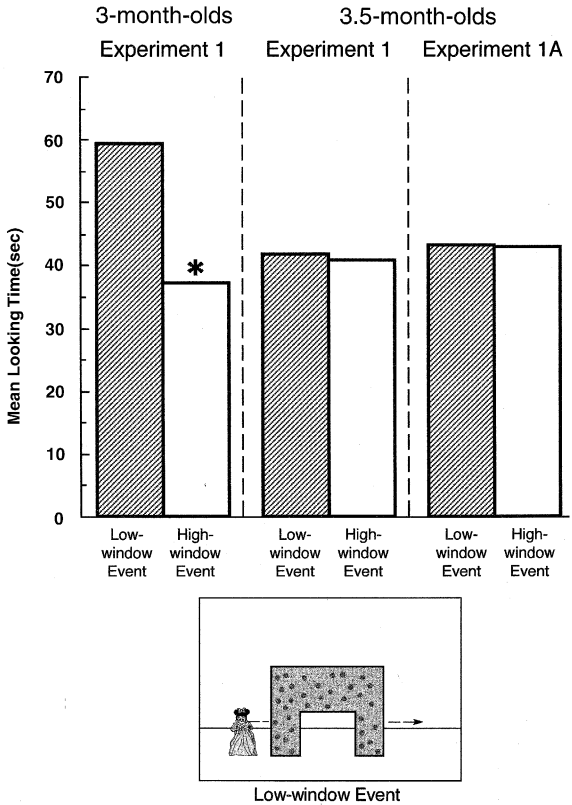

Fig. 4. Mean looking times of the 3- and 3.5-month-olds in Experiments 1 and 1A at the low- and high-window test events.

looked about equally at the two events, $F(1,16) = 0.02$ (low-window: $M = 41.9$, $SD = 18.3$; high-window: $M = 40.9$, $SD = 25.7$). Examination of the individual infants' mean looking times (see Fig. 5) yielded similar findings: Whereas 9 of the 10 3-month-old infants looked longer at the low- than at the high-window event, Wilcoxon $T = 51$, $p < .01$, only 5 of the 10 3.5-month-old infants did so, Wilcoxon $T = 28$, $p > .05$.

The ANOVA also yielded a significant interaction between order and event, $F(1,16) = 6.34$, $p < .025$. Post hoc comparisons indicated that the infants who saw the low-window event first looked reliably longer at this event ($M = 53.2$, $SD = 18.6$) than at the high-window event ($M = 31.4$, $SD = 17.4$), $F(1,16) = 14.2$, $p < .0025$; in contrast, the infants who saw the high-window event first tended to look equally at the two events (low-window: $M = 47.9$, $SD = 22.5$; high-window: $M = 46.7$, $SD = 24.2$), $F(1,16) = 0.04$. Because this interaction did not include age, it does not bear on the present hypotheses and is not discussed further.

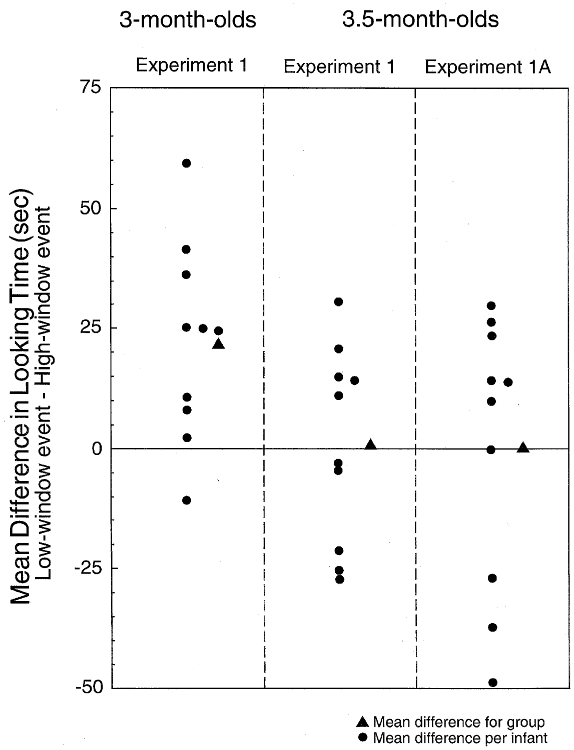

Fig. 5. Difference in the mean looking times of the 3- and 3.5-month-olds in Experiments 1 and 1A at the low- and high-window test events. Each dot represents an individual infant.

2.2.1. Further results: Experiment 1A

The 3-month-old infants in Experiment 1 looked reliably longer at the low- than at the high-window test event, but the 3.5-month-old infants tended to look equally at the events. Because the results with the older infants diverged from the norm—developmental findings typically involve older infants responding with prolonged looking to violations and younger infants not, rather than the reverse—an additional group of 3.5-month-old infants were tested in Experiment 1A using the same procedure as in Experiment 1. The participants were 10 healthy term infants, 5 male and 5 female, ranging in age from 102 to 130 days (M = 114.7 days). An additional 9 infants were tested but eliminated, 6 because of fussiness, 2 because of drowsiness, and 1 because the infant looked for 90 s on 3 test trials. Four infants failed to satisfy the habituation criterion within 9 trials; the other 6 infants took an average of 6.8 trials to reach the criterion. During the test trials, 4 infants saw the low-window event first and 6 saw the high-window event first. Interobserver agreement was calculated for 9 of the infants (only one observer was present for 1 infant) and averaged 92.4% per test trial per infant. Eight of the 36 test trials for which two observers were present (9 infants $\times$ 4 test trials) ended because the infant had looked at the event for 90 s; the average looking time recorded by the secondary observer on these trials was 90.9 s. The secondary observer agreed that the infant was not looking at the end of 25 of the 28 trials that ended with a 2-s look away; the average look away registered by the secondary observer at the end of these trials was 1.7 s. Preliminary analyses of the infants' looking times during the test trials revealed no significant interaction between sex and event, $F(1,8) = 0.27$; the data were therefore collapsed across sex in subsequent analyses.

The infants' looking times at the test events (see Fig. 4) were averaged and analyzed by means of a 2×2 ANOVA, with order (low- or high-window event first) as a between-subjects factor and with event (low- or high-window) as a within-subject factor. The main effect of event was not significant, $F(1,8) = 0.02$, indicating that the 3.5-month-old infants in Experiment 1A, like those in Experiment 1, tended to look equally at the low-($M = 43.3$, $SD = 17.0$) and high-window ($M = 42.9$, $SD = 26.3$) events. No other effect was significant. Examination of the individual infants' mean looking times yielded similar findings (see Fig. 5): Only 6 the 10 infants in Experiment 1A looked longer at the low- than at the high-window event, Wilcoxon $T = 28$, $p > .05$.

2.3. Discussion

The 3-month-old infants in Experiment 1 looked reliably longer at the low- than at the high-window test event. This result suggested that, when viewing the low-window event, the infants (1) believed that the mouse continued to exist when behind the screen, (2) realized that the mouse could not disappear behind one edge of the screen and reappear from behind the other edge without traveling the distance between them, and (3) expected the mouse to appear in the window and were surprised when it failed to do so.[6] The present result, combined with the prior findings (discussed in Section 1) that (1) 2.5-month-old infants tested with a similar task tended to

[6] Why did the 3-month-old infants in Experiment 1 not simply conclude, when watching the low-window test event, that the mouse hopped above the window (recall that two adults assumed that the mouse was lifted up and across the screen)? The answer to this question is unclear. Perhaps the infants were led by the habituation trials to assume that the mouse could only follow a simple lateral trajectory. Perhaps the infants believed that self-moving objects with a rigid, repetitive motion (e.g., like ceiling fans) are typically incapable of hopping. Or perhaps the infants possessed a general expectation that moving objects tend to pursue their same trajectories when occluded. Further research is needed to shed light on infants' expectations about objects' visible and hidden trajectories.

look equally at the low- and high-window test events (Aguiar & Baillargeon, 1999) and (2) unlike 3.5-month-old infants, 3-month-old infants tested with the carrot task tended to look equally at the tall- and short-carrot test events (Baillargeon & DeVos, 1991), suggested that an important change takes place at about 3 months of age in infants' knowledge of when objects should and should not be occluded. Specifically, infants begin to attend to the lower edges of occluders and expect objects to remain continuously hidden when passing behind occluders with continuous but not discontinuous lower edges. Infants now expect an object to become temporarily visible when passing behind an occluder with an opening extending from its lower edge.

In contrast to the 3-month-old infants, the 3.5-month-old infants in Experiments 1 and 1A tended to look equally at the low- and high-window test events. Our interpretation of this negative result was that, like the 3-month-old infants, the 3.5-month-old infants expected the mouse to become visible when passing behind the screen with the low window. Unlike the younger infants, however, the older infants were able to generate an explanation for the mouse's failure to appear in the low window. Specifically, they inferred that two identical mice were involved in the event, one traveling to the left and one to the right of the window. The infants' responses were thus similar to those (described in Section 1) of the 4-month-old infants tested by Spelke (Spelke & Kestenbaum, 1986; Spelke et al., 1995a) and of the 5.5-month-old infants tested by Baillargeon (1994b).

According to the preceding account, the discrepancy between the test responses of the 3- and 3.5-month-old infants in Experiments 1 and 1A thus stemmed from that fact that, although the infants in *both* age groups detected the violation in the low-window event, *only* the older infants were able to generate a two-mouse explanation for the event. The younger infants, who could not make sense of the event, remained surprised by it and thus looked reliably longer at it than at the high-window event. Whatever surprise the older infants experienced when first shown the low-window event rapidly dissipated, resulting in equal looking times overall at the two test events.[7]

To test this account, six additional experiments were carried out, three with 3.5-month-old infants (Experiments 2, 3, and 4) and three with 3-month-old infants (Experiments 5, 6, and 7).

[7] Following Experiment 4, we explore the question of whether the 3.5-month-old infants in the present research were initially surprised by the low-window test event, when they first noticed that the mouse did not appear in the window. Recall that the adults who were shown this event reported being initially surprised by it, though they then had no difficulty producing an explanation for it. We speculated that our infants might have gone through a similar process and experienced a brief initial surprise that disappeared when they arrived at a satisfactory explanation for the event.

3. Experiment 2

Our interpretation of the responses of the 3.5-month-old infants in Experiments 1 and 1A was that they showed little surprise at the low-window test event because they were readily able to generate a two-mouse explanation for the event. Because the screen was never lowered, the infants had no information contradicting the notion that two mice might be present in the apparatus. A two-mouse explanation was thus entirely consistent with the information available to the infants.

In Experiment 2, 3.5-month-old infants were given information that only *one* mouse was present in the apparatus. The infants saw the same habituation and test events as in Experiment 1, except that the screen was lowered at the start of each trial to reveal a single mouse (see Fig. 6). After the screen was raised, the events proceeded exactly as before (unseen by the infants, an experimenter introduced a second mouse into the apparatus). We reasoned that the infants would now no longer be able to produce a two-mouse explanation for the low-window test event; although it was possible that they might resort to more complex alternative explanations (e.g., a second mouse was surreptitiously slipped behind the screen), such constructions seemed beyond the problem solving abilities of young infants. Therefore, we predicted that, lacking a viable explanation for the low-window event, the infants would show surprise at the event, as did the 3-month-old infants in Experiment 1.

3.1. Method

3.1.1. Participants

Participants were 10 healthy term infants, 5 male and 5 female, ranging in age from 101 to 119 days ($M = 109.9$ days). An additional 7 infants were tested but eliminated, 4 because of fussiness, 1 because the infant looked for 90 s on three test trials, and 2 because the primary observer had difficulty following the direction of the infant's gaze.

3.1.2. Apparatus

The apparatus used in Experiment 2 was identical to that in Experiment 1 with two exceptions. First, the habituation and test screens were mounted on a wooden dowel 120 cm long and 1.25 cm in diameter that lay on the apparatus floor, 10 cm in front of the back wall. The dowel protruded through small holes in each side wall; by rotating a metal knob attached to the dowel's right end, an experimenter could rotate the screen 90° upward. Second, a hidden door 12 cm high and 8 cm wide was cut in the back wall of the apparatus, behind the right edge of the habituation and test screens. An experimenter used this door to surreptitiously insert the second mouse after the screen was raised.

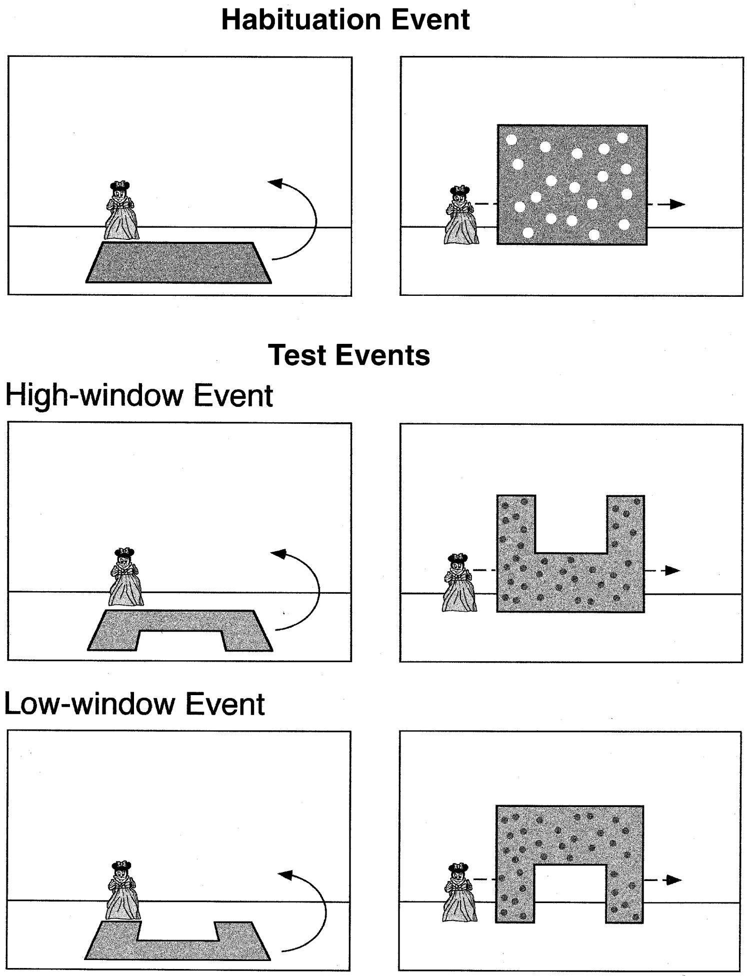

Fig. 6. Schematic drawing of the habituation and test events in Experiment 2.

3.1.3. Events

The events in Experiment 2 were identical to those in Experiment 1, except that a brief pretrial now preceded each habituation and test trial. Three experimenters worked in concert to produce this pretrial: The first rang the bell and slid the mice along the track, the second rotated the screen, and the third inserted the second mouse into the apparatus.

3.1.3.1. Pretrial preceding each habituation trial. At the start of the pretrial that preceded each habituation trial, the windowless purple screen lay flat on the apparatus floor, toward the infant, and a mouse stood visible behind the left edge of the screen. The first experimenter rang the bell once per second until the computer signaled that the infant had looked at the area behind the screen for 3 cumulative seconds. This was done to help the infants notice that only one mouse was present in the apparatus. Next, the second experimenter rotated the screen 90° upward (2 s). After a 1-s pause, the first experimenter slid the mouse from behind the left edge of the screen to its starting position in the left corner of the apparatus (2 s). At the same time, the third experimenter inserted the second mouse into the apparatus and placed it behind the right edge of the screen. After a 1-s pause, the habituation trial proceeded exactly as in Experiment 1.

3.1.3.2. Pretrial preceding each low- and high-window test trial. The pretrial that preceded each low- and high-window test trial was identical to the habituation pretrial except for the screen used: The screen with the low window was used in the low-window pretrial and the screen with the high window in the high-window pretrial.

3.1.4. Procedure

The procedure used in Experiment 2 was identical to that in Experiment 1. Only 1 infant failed to satisfy the habituation criterion within 9 trials; the remaining 9 infants took an average of 7.3 trials to reach the criterion. Interobserver agreement during the test trials was measured for all of the infants and averaged 92.3% per trial per infant. Based on the primary observer's responses, 9 of the 40 test trials (10 infants × 4 test trials) ended because the infant had looked at the event for 90 s; the average looking time recorded by the secondary observer on these trials was 88.0 s. The secondary observer agreed that the infant was not looking at the end of 27 of the 31 trials that ended with a 2-s look away; the average look away registered by the secondary observer at the end of these trials was 2.0 s. Preliminary analyses of the infants' looking times during the test trials revealed no significant interaction between sex and event, $F(1,8) = 0.75$; the data were therefore collapsed across sex in subsequent analyses.

3.2. Results

Fig. 7 shows the mean looking times of the infants in Experiment 2 at the test events. It can be seen that the infants looked longer at the low- than at the high-window event.

The infants' looking times at the test events were averaged and analyzed as in Experiment 1A. The analysis revealed a significant main effect of event, $F(1,8) = 8.62, p < .025$, indicating that the infants looked reliably longer at the low- ($M = 58.6$, $SD = 22.3$) than at the high-window ($M = 29.4$, $SD = 11.9$) event. No other effect was significant. Examination of the individual infants' mean looking times yielded similar findings (see Fig. 8): Of

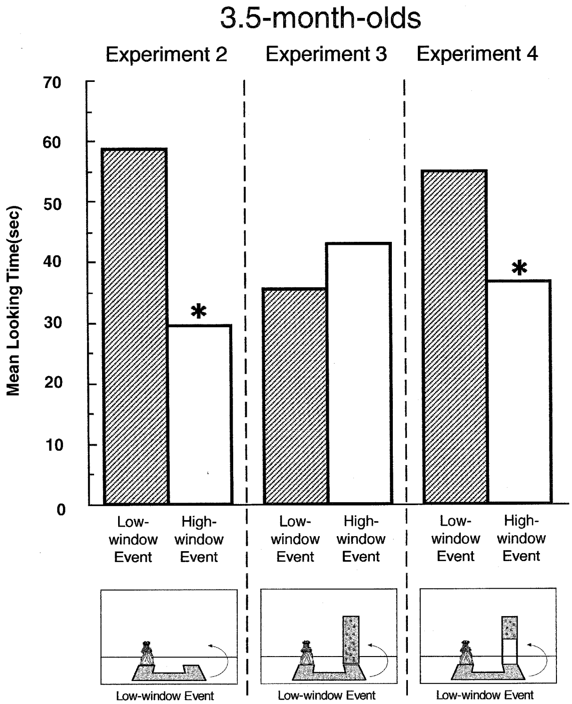

Fig. 7. Mean looking times of the 3.5-month-olds in Experiments 2, 3, and 4 at the low- and high-window test events.

the 10 infants in Experiment 2, 9 looked longer at the low- than at the high-window event, Wilcoxon $T = 49$, $p < .05$.

3.3. Discussion

The 3.5-month-old infants in Experiment 2 looked reliably longer at the low- than at the high-window test event. This positive finding suggested that, when shown the low-window event, the infants (1) believed that the mouse continued to exist when behind the screen, (2) realized that the mouse could not disappear behind one edge of the screen and reappear from behind the other edge without traveling the distance between them, and (3) expected the mouse to appear in the window and were surprised when it failed to do so.

The results of Experiment 2 also provided strong support for the claim that the 3.5-month-old infants in Experiments 1 and 1A tended to look equally at the low- and high-window test events because they were able to produce a two-mouse explanation for the low-window event. In Experiments 1 and 1A, the screen was never lowered, so that a two-mouse expla-

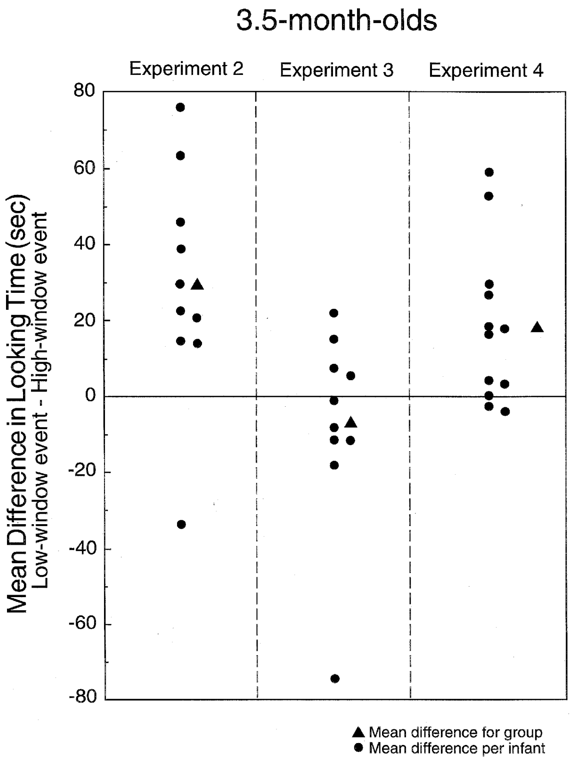

Fig. 8. Difference in the mean looking times of the 3.5-month-olds in Experiments 2, 3, and 4 at the low- and high-window test events. Each dot represents an individual infant.

nation was entirely consistent with the information available to the infants. In Experiment 2, in contrast, the screen was lowered at the start of each trial to reveal a single mouse; the infants were thus given information invalidating a two-mouse explanation. Together, the results of Experiments 1, 1A, and 2 thus suggested that the 3.5-month-old infants consistently generated a two-mouse explanation for the low-window event, *unless* such an explanation was contradicted by unambiguous information that only one mouse was present in the apparatus. When this occurred, the infants were no longer able to produce a plausible explanation for the low-window event and they therefore remained surprised by it, resulting in reliably longer looking at it than at the high-window event.

In Experiment 3, we sought additional evidence that 3.5-month-old infants will generate a two-mouse explanation for the low-window test event as long as this explanation is not inconsistent with the information available to them. The infants saw habituation and test events identical to those in Experiment 2 with one exception: When the screen was lowered at the start of each trial, the infants saw a mouse on the left and a *narrow screen* on the right (see Fig. 9). This narrow screen was sufficiently large to hide a second mouse. We reasoned that, with the introduction of the narrow screen, a two-mouse explanation was again plausible for the low-window event. Upon observing that the mouse reappeared on the far side of the screen without appearing in the window, the infants could infer that a second mouse must have been hidden behind the narrow screen. If the infants were indeed capable of drawing such an inference, then they should perform exactly like the 3.5-month-old infants in Experiments 1 and 1A; that is, they should tend to look equally at the low- and high-window events.

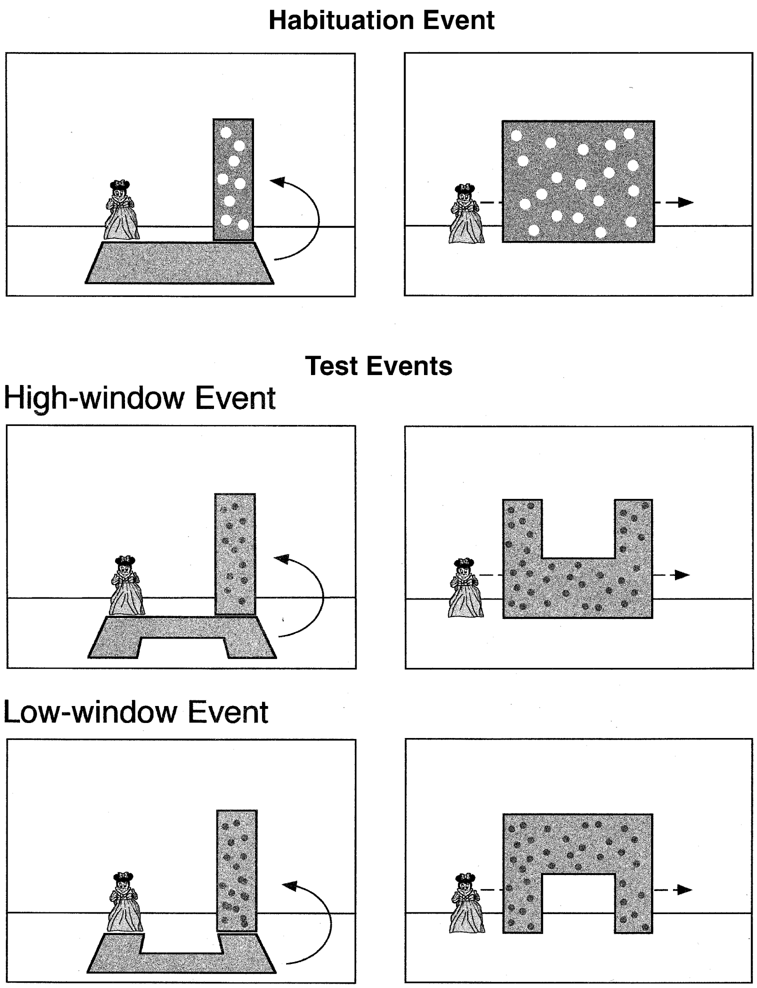

Fig. 9. Schematic drawing of the habituation and test events in Experiment 3.

4. Experiment 3

4.1. Method

Participants. Participants were 10 healthy term infants, 5 male and 5 female, ranging in age from 101 to 126 days ($M = 108.3$ days). An additional 11 infants were tested but eliminated, 8 because of fussiness, 1 because the infant looked for 90 s on three test trials, 1 because of inattentiveness, and 1 because the primary observer had difficulty following the direction of the infant's gaze.

Apparatus and events. The apparatus and events used in Experiment 3 were identical to those in Experiment 2, except that a narrow screen stood behind the right edge of the habituation or test screen. The narrow screen was made of cardboard, was supported by a metal frame, and was 30 cm high and 10 cm wide (it was sufficiently large to hide a second mouse). In the habituation trials, the narrow screen was dark purple with large yellow dots; in the test trials, the narrow screen was bright green with small red dots. The narrow screen was fully hidden when the habituation or test screen was raised.

Procedure. The procedure used in Experiment 3 was identical to that in Experiment 2. Two infants failed to satisfy the habituation criterion within 9 trials; the remaining 8 infants took an average of 6.5 trials to reach the criterion. Interobserver agreement during the test trials was measured for all of the infants and averaged 92.9% per trial per infant. Based on the primary observer's responses, 6 of the 40 test trials (10 infants $\times$ 4 test trials) ended because the infant had looked at the event for 90 s; the average looking time recorded by the secondary observer on these trials was 89.1 s. The secondary observer agreed that the infant was not looking at the end of 30 of the 34 trials that ended with a 2-s look away; the average look away registered by the secondary observer at the end of these trials was 1.9 s. Preliminary analyses of the infants' looking times during the test trials revealed no significant interaction between sex and event, $F(1, 8) = 0.29$; the data were therefore collapsed across sex in subsequent analyses.

4.2. Results

Fig. 7 shows the mean looking times of the infants in Experiment 3 at the low- and high-window test events. It can be seen that the infants looked about equally at the two events.

The infants' looking times at the test events were averaged and analyzed as in Experiment 1A. The main effect of event was not significant, $F(1, 8) = 0.77$, indicating that the infants tended to look equally at the low- ($M = 35.5$, $SD = 18.7$) and high-window ($M = 43.0$, $SD = 24.1$) events. No other effect was significant. Examination of the individual infants' mean looking times yielded similar findings (see Fig. 8): Only 4 of the 10 infants looked longer at the low- than at the high-window event, Wilcoxon $T = 21$, $p > .05$.

4.3. Discussion

The infants in Experiment 3 tended to look equally at the low- and high-window test events. This result contrasted sharply with the positive result of Experiment 2 and suggested that the infants readily produced a two-mouse explanation for the low-window event as long as it was not flatly contradicted by the information available to them. When the low-window screen was lowered to reveal a mouse and a narrow screen, the infants did not show surprise at the event, suggesting that they inferred that a second mouse must have been hidden behind the narrow screen. In contrast, when the low-window screen was lowered to reveal only a mouse—rendering a two-mouse explanation implausible—the infants did show surprise at the event.

There was, however, an alternative interpretation for the results of Experiment 3. The infants could have looked equally at the low- and high-window test events simply because having to represent two distinct objects (i.e., the mouse and the narrow screen) behind the habituation and test screens was too taxing for them. As a result, the infants processed the events only superficially and thus failed to distinguish between them.

To evaluate this possibility, a final experiment was run with 3.5-month-old infants. The infants in Experiment 4 saw the same habituation and test events as in Experiment 3, except that the narrow screen had a window in its lower half; the window was empty, making it clear that no object—such as a second mouse—lurked behind the narrow screen (see Fig. 10). We reasoned that if the infants in Experiment 3 tended to look equally at the low- and high-window events because they were able to posit the presence of a second mouse behind the narrow screen, then the infants in Experiment 4, who could not generate the same explanation, should show a reliable preference for the low- over the high-window event. On the other hand, if the infants in Experiment 3 were overwhelmed by the presence of two distinct objects behind the habituation and test screens, then the infants in Experiment 4 should be similarly confused and thus should also look about equally at the low- and high-window events.

5. Experiment 4

5.1. Method

Participants. Participants were 12 healthy term infants, 6 male and 6 female, ranging in age from 102 to 121 days ($M = 110.3$ days). An additional

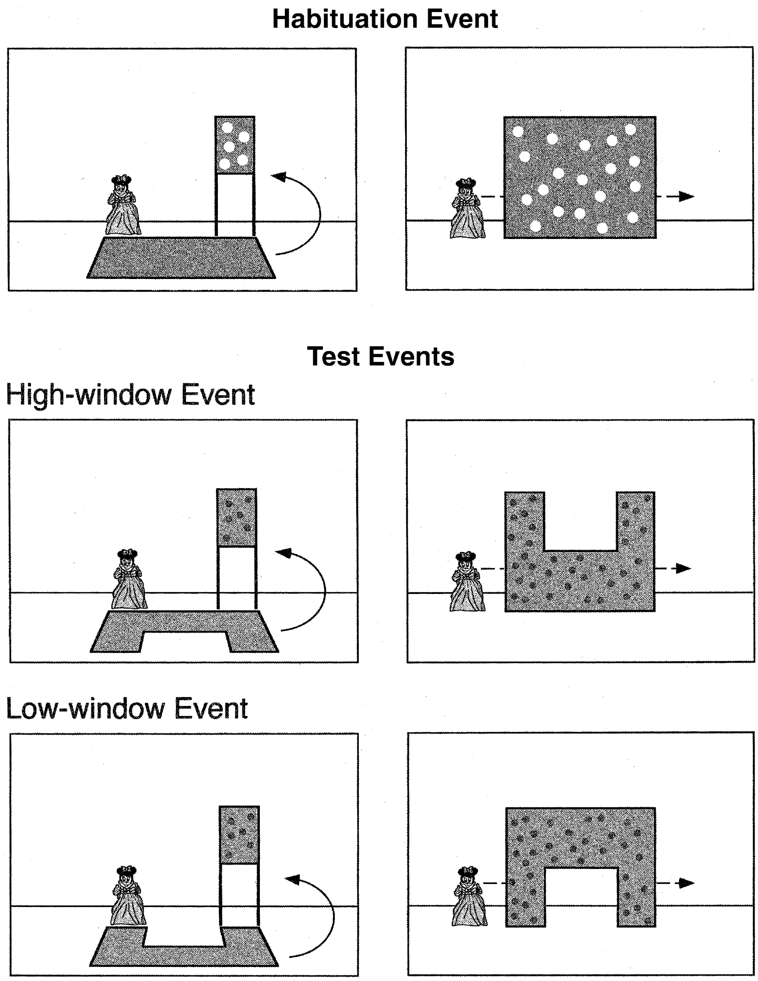

Fig. 10. Schematic drawing of the habituation and test events in Experiment 4.

6 infants were tested but eliminated, 2 because of fussiness, 2 because they looked for 90 s on three test trials, 1 because the infant failed to track the mouse along its entire trajectory in at least one of the habituation trials, and 1 because the primary observer had difficulty following the direction of the infant's gaze.

Apparatus and events. The apparatus and events used in Experiment 4 were identical to those in Experiment 3, except that the narrow screen used in the habituation and test events had a window 15 cm high and 8 cm wide centered in its lower half.

Procedure. The procedure used in Experiment 4 was identical to that in Experiment 3. Four infants failed to satisfy the habituation criterion within 9 trials; the remaining 8 infants took an average of 7.5 trials to reach the criterion. Interobserver agreement during the test trials was measured for all of the infants and averaged 94.7% per trial per infant. Based on the primary observer's responses, 8 of the 48 test trials (12 infants $\times$ 4 test trials) ended because the infant had looked at the event for 90 s; the average looking time recorded by the secondary observer on these trials was 89.0 s. The secondary observer agreed that the infant was not looking at the end of all 40 trials that ended with a 2-s look away; the average look away registered by the secondary observer at the end of these trials was 1.9 s. Preliminary analyses of the infants' looking times during the test trials revealed no significant interaction between sex and event, $F(1, 10) = 0.06$; the data were therefore collapsed across sex in subsequent analyses.

5.2. Results

Fig. 7 shows the mean looking times of the infants in Experiment 4 at the test events. It can be seen that the infants looked longer at the low- than at the high-window event.

The infants' looking times at the test events were averaged and analyzed as in Experiment 1A. The main effect of event was significant, $F(1, 10) = 10.14$, $p < .01$, indicating that the infants looked reliably longer at the low- ($M = 54.9$, $SD = 30.4$) than at the high-window ($M = 36.6$, $SD = 23.2$) event. No other effect was significant. Examination of the individual infants' mean looking times yielded similar findings (see Fig. 8): Nine of the 12 infants in Experiment 3 looked longer at the low- than at the high-window event, Wilcoxon $T = 70$, $p < .025$.

Comparisons among Experiments 2, 3, and 4. In a final set of analyses, we compared the looking times at the low- and high-window test events of the infants in Experiments 2, 3, and 4 (see Figs. 7 and 8). In all of these experiments, the screen was lowered at the start of each trial to reveal either one mouse (Experiment 2), one mouse and one narrow screen (Experiment 3), or one mouse and one narrow screen with an empty low window (Experiment 4). The infants' looking times were averaged and compared by means of a $3 \times 2 \times 2$ ANOVA, with experiment (2, 3, or 4) and order (low- or high-window event first) as between-subjects factors and with event (low- or high-window) as a within-subject factor. The analysis yielded a significant main effect of event, $F(1, 26) = 8.28$, $p < .01$, and a significant experiment $\times$ event interaction, $F(2, 26) = 5.24$, $p < .025$. Planned comparisons confirmed the results reported previously: The infants looked reliably longer at the low- than at the high-window event in Experiment 2, $F(1, 26) = 12.45$, $p < .0025$, and in Experiment 4, $F(1, 26) = 5.94$, $p < .025$, but not in Experiment 3, $F(1, 26) = 0.83$.

5.3. Discussion

In Experiment 4, the infants saw a mouse and a narrow screen with an empty low window in the pretrial preceding each trial; the infants looked reliably longer at the low- than at the high-window test event. The infants' responses were thus similar to those of the infants in Experiment 2, who saw only one mouse behind the screen during the pretrials, but differed from those of the infants in Experiment 3, who saw a mouse and a windowless narrow screen in the pretrials, and also from those of the 3.5-month-old infants in Experiments 1 and 1A, who did not receive pretrials and never saw the screen lowered to the apparatus floor.

Together, these results indicated that the infants generated a two-mouse explanation for the low-window test event when such an explanation was plausible given the facts available to them, but not otherwise. The infants looked equally at the two test events (1) when the screen was never lowered, leaving open the possibility that a second mouse was hidden behind it, or (2) when the screen was lowered in each pretrial to reveal a mouse and a narrow screen sufficiently large to hide a second mouse. In contrast, the infants looked reliably longer at the low- than at the high-window event when the screen was lowered in the pretrials to reveal (1) only a mouse or (2) a mouse and a narrow screen with an empty low window, making it clear that no object (and especially no second mouse) lurked behind it.

The present results thus confirmed prior results that infants ages 5.5 months (Baillargeon, 1994b) and 4 months (Spelke & Kestenbaum, 1986; Spelke et al., 1995a) can posit additional occluded objects to make sense of (at least some) events that would otherwise violate their knowledge of when objects should and should not be occluded. The present research also extended these results in two ways: First, by showing that even younger, 3.5-month-old, infants are able to infer the existence of additional occluded objects; and second, by shedding further light on the nature of this ability. The infants in Experiments 2–4 remembered the information provided during the pretrials and used this information to constrain their reasoning. They inferred that a second mouse was present to make sense of the low-window event *only* when such an inference was consistent with their representations of the objects—visible or hidden—in the apparatus.

Additional analyses of the 3.5-month-old infants' data. The 3.5-month-old infants in Experiments 1–4 produced two distinct patterns of responding: Whereas the infants in Experiments 2 and 4 showed overall surprise at the low-window test event, those in Experiments 1, 1A, and 3 did not. We speculated that, even though the infants in Experiments 1, 1A, and 3 showed no *overall* surprise at the low-window event, they might still have displayed some *initial* surprise that dissipated when they arrived at the two-mouse explanation for the event. Recall that adults were initially surprised by the low-window event (as indicated by their ratings), but rapidly went on to generate an explanation for it. In light of these results, it seemed plausible that the 3.5-month-old infants in Experiments 1, 1A, and 3 also were surprised when they first noticed that the mouse failed to appear in the screen's low window, before they succeeded in making sense of this failure.

To investigate this possibility, we conducted two additional sets of analyses (see Fig. 11). In the first, we examined the infants' responses during

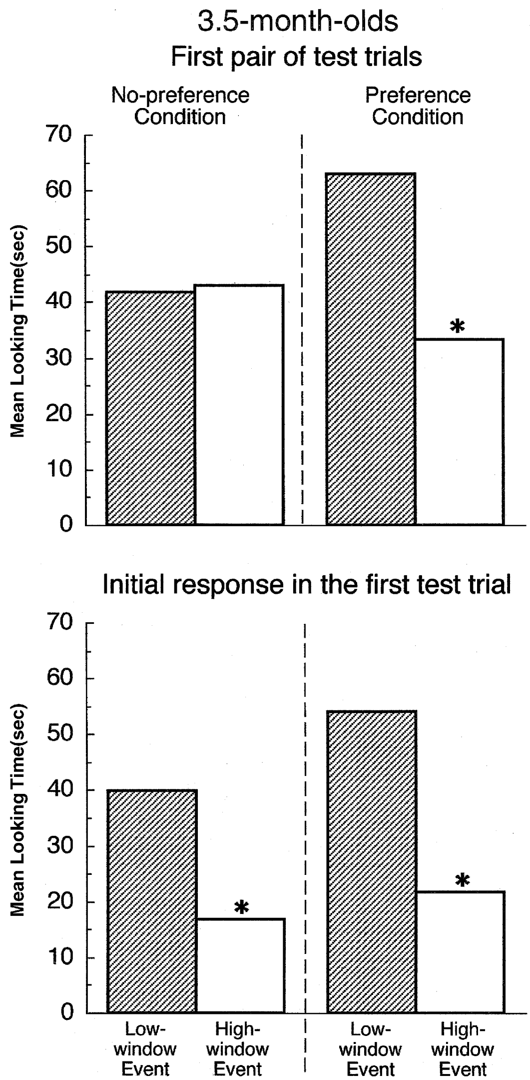

Fig. 11. Mean looking times of the 3.5-month-olds in Experiments 1, 1A, and 3 (no-preference condition) and in Experiments 2 and 4 (preference condition) in the first pair of test trials (top) and in their initial response during the first test trial (bottom).

the *first pair of test trials*; recall that in all of the preceding analyses, the infants' responses were always averaged across both test pairs. It seemed possible that different results might emerge when the data from the first test pair were considered alone. In this analysis, the 3.5-month-old infants in Experiments 1, 1A, and 3 were grouped into one condition (no-preference condition; $n = 30$), and the infants in Experiments 2 and 4 were grouped into another condition (preference condition; $n = 22$). The infants' looking times during the first test pair were compared by means of a $2 \times 2 \times 2$ ANOVA, with condition (no-preference or preference) and order (low- or high-window event first) as between-subjects factors and with event (low- or high-window) as a within-subject factor. The analysis yielded a significant main effect of event, $F(1,48) = 5.76$, $p < .025$, and a significant condition × event interaction, $F(1,48) = 6.68$, $p < .025$. Planned comparisons indicated that the preference infants looked reliably longer at the low- ($M = 62.9$, $SD = 31.8$) than at the high-window ($M = 33.4$, $SD = 26.3$) event, $F(1,48) = 10.78$, $p < .0025$, but that the no-preference infants tended to look equally at the two events, $F(1,48) = 0.02$ (low-window: $M = 41.7$, $SD = 30.0$; high-window: $M = 42.9$, $SD = 32.1$). Similar patterns of results were thus obtained when the data from both test pairs or from only the first test pair were examined.

In the second set of analyses, we focused on the infants' *initial response during the first test trial*. Since each test trial ended when the infant looked away for 2 consecutive seconds, or looked 90 s without looking away for 2 consecutive seconds, it was possible for an infant to look away and back several times during a trial. We speculated that an analysis focusing on the infants' first looks at the low- and high-window test events might perhaps produce a different pattern of results than that obtained when the data from the first test pair or from both test pairs were analyzed.

One concern with comparing the infants' first looks at the low- and high-window test events was that such a comparison could be meaningful only if the infants had gathered sufficient information about the events to distinguish between them (e.g., an infant who looked at the low-window event for 1 s and then looked away would have seen too little of the event to respond to it appropriately). To address this concern, each infant's performance during the first half (7 s) of the first event cycle was scrutinized. Infants were retained in the analysis *only* if they (1) looked for at least 0.5 cumulative seconds during the first 3 s of the event, when the mouse was at least partly visible to the left of the screen, (2) looked continuously during the next 2 s, when the mouse was out of view behind the screen, and finally (3) looked for at least 0.5 cumulative seconds during the next 2 s, when the mouse emerged from behind the screen and moved to the apparatus's right wall. These criteria helped ensure that the infants realized that the mouse did not appear in the window (second criterion), even though it was following its typical trajectory across the apparatus (first and third criteria).

In all, 17 of the 22 infants in the preference condition and 24 of the 30 infants in the no-preference condition met the criteria described above; 19 of the infants (7 in the preference and 12 in the no-preference condition) saw the low-window test event, and 22 infants (10 in the preference and 12 in the no-preference condition) saw the high-window test event. The duration of each infant's first look was calculated beginning immediately after the infant satisfied the third criterion (i.e., cumulated 0.5 s of looking when the mouse was visible to the right of the screen) and ending when the infant looked away from the event for 0.5 consecutive s. The infants' first looks were analyzed by means of a 2×2 ANOVA, with condition (preference or no-preference) and event (low- or high-window) as between-subjects factors. The analysis revealed a significant main effect of event, $F(1,37) = 12.28$, $p < .0025$, and no significant interaction between event and condition, $F(1,37) = 0.32$. Planned comparisons indicated that (1) in the preference condition, the infants who saw the low-window event ($M = 54.0$, $SD = 31.4$) produced reliably longer first looks than did the infants who saw the high-window event ($M = 21.7$, $SD = 17.7$), $F(1,37) = 6.99$, $p < .025$, and (2) the same pattern held in the no-preference condition, $F(1,37) = 5.29$, $p < .05$ (low-window: $M = 39.9$, $SD = 28.9$; high-window: $M = 16.7$, $SD = 20.7$).[8]

5.4. Discussion

The 3.5-month-old infants in Experiments 1, 1A, and 3 looked reliably longer at the low- than at the high-window test event when first shown the events, but not thereafter. Analyses focusing on the infants' cumulative responses during the first pair or both pairs of test trials produced negative results. Only the analysis focusing on the infants' *first looks* at the events yielded positive results. These findings suggested that, like the adults in Experiment 1, the infants were initially surprised by the mouse's failure to appear in the low window, but were soon able to produce a two-mouse explanation for the event; the infants' surprise at the event then vanished, resulting in equal looking times overall at the two events.

In marked contrast, the infants in Experiment 2 and 4 showed a reliable preference for the low- over the high-window event (1) in their first looks at the events, (2) in their cumulative responses in the first test pair, and (3) in their cumulative responses in the first and second test pairs combined. These results suggested that, like the infants in Experiments 1, 1A, and 3, those in Experiments 2 and 4 were surprised when they first saw that the mouse did

[8] One infant in the no-preference condition who saw the high-window event in his first test trial looked away immediately after satisfying the third criterion, resulting in a looking time of 0 s. The analysis was redone without this infant and produced exactly the same results.

not become visible when passing behind the screen with the low window. Unlike these other infants, however, the infants in Experiments 2 and 4 could not produce a two-mouse explanation for the event, and so they remained surprised by it throughout the test trials.

The results concerning the infants' first looks at the low- and high-window test events are interesting not only because they deepen our understanding of the infants' responses to the events, but also because they reveal the robustness of the infants' event representations. Consider, in particular, Experiments 2, 3, and 4, in which the screen was lowered in the pretrial preceding each trial. According to the analysis advanced above, the infants in all three experiments were surprised initially by the low-window event and sought an explanation for it. In this search, the infants were clearly affected by their representations of the object(s) that had been revealed behind the screen in the pretrial. On the basis of these representations, the infants determined either that (1) a second mouse must have been hidden behind the narrow screen (Experiment 3) or (2) no second mouse was present in the apparatus (Experiments 2 and 4). Had the infants in Experiments 2 and 4 forgotten the information provided in each pretrial, they would presumably have performed like the infants in Experiments 1 and 1A, who never saw the screen lowered and thus were able to assume that a second mouse must be lurking behind it. Similarly, had the infants in Experiment 3 forgotten the presence of the narrow screen next to the mouse, they would most likely have performed like the infants in Experiment 2, who saw a single mouse behind the screen. Together, these results suggest that the infants in the present research not only formed fairly precise representations of the object(s) present behind the screen in each pretrial, but were able to remember this information for a considerable time period. The mean first look of the infants in Experiment 3 who saw the low-window event in their first test trial was 42.7 s (thus very similar to the 39.9 s average reported above for all of the no-preference infants). If one makes the plausible assumption that the infants generated their two-mouse explanation toward the *end* rather than the beginning of their first look at the event, then it becomes evident just how long the infants had to maintain their representations of the two objects (mouse, narrow screen) behind the screen in order to arrive at their explanation for the event.

6. Experiment 5

The 3-month-old infants in Experiment 1 looked reliably longer at the low- than at the high-window test event. This positive result contrasted with two negative results discussed in Section 1: (1) the negative result obtained with the 2.5-month-old infants tested with habituation and test events similar to those in Experiment 1 (Aguiar & Baillargeon, 1999), and (2) the negative result obtained with the 3- but not the 3.5-month-old infants in the carrot experiment (Baillargeon & DeVos, 1991; see Fig. 3). Together, these results suggested that, by 3 months of age, infants have begun to progress beyond their initial concept of when objects should and should not be occluded, but have not yet reached the same level of understanding as 3.5-month-old infants. More specifically, the results suggested that 3-month-old infants no longer simply expect an object to be hidden when behind another object: They now consider the lower—though still not the upper—edges of occluders and expect objects to become temporarily visible when passing behind occluders with discontinuities in their lower edges.

There was, however, an alternative interpretation for the discrepancy between the positive results obtained in Experiment 1 and the negative results obtained by Baillargeon and DeVos (1991) in their carrot experiment. Because there were multiple differences in the stimuli and procedures used in the two experiments, it could be argued that the negative results of Baillargeon and DeVos stemmed from the fact that their task was less sensitive or less well-suited to the testing of 3-month-old infants than the present task. To give an example, the maximum length of each habituation and test trial was 90 s in Experiment 1 but only 60 s in the carrot task; hence it could be that the infants in the latter task were not sufficiently familiarized with the experimental situation to reason about it appropriately.

To examine this alternative interpretation, an additional group of 3-month-old infants was tested in Experiment 5. The infants saw habituation and test events identical to those in Experiment 1, except that the low-window test event was replaced by a different event (see Fig. 12). As in the high-window test event, the screen had a window extending from its upper edge; however, this high window was enlarged to such an extent that only a short strip remained beneath the window (large-high-window event). Although the violation shown in this new event was not as great as that in the low-window event (recall that the entire mouse failed to appear in the window), it was still considerable (over two-thirds of the mouse failed to become visible when passing behind the screen).

We reasoned that positive results in Experiment 5 would point to a different developmental sequence than that proposed above. According to this sequence, 2.5-month-old infants would simply expect any object to be hidden when behind any occluder; at about 3 months of age, infants would begin to consider both the upper *and* the lower edges of occluders in judging whether objects should remain hidden or become temporarily visible when passing behind the occluders. In contrast, negative results in Experiment 5 would support the conclusion that infants proceed through a longer developmental sequence and attend first to the lower and only after some time the upper edges of occluders.

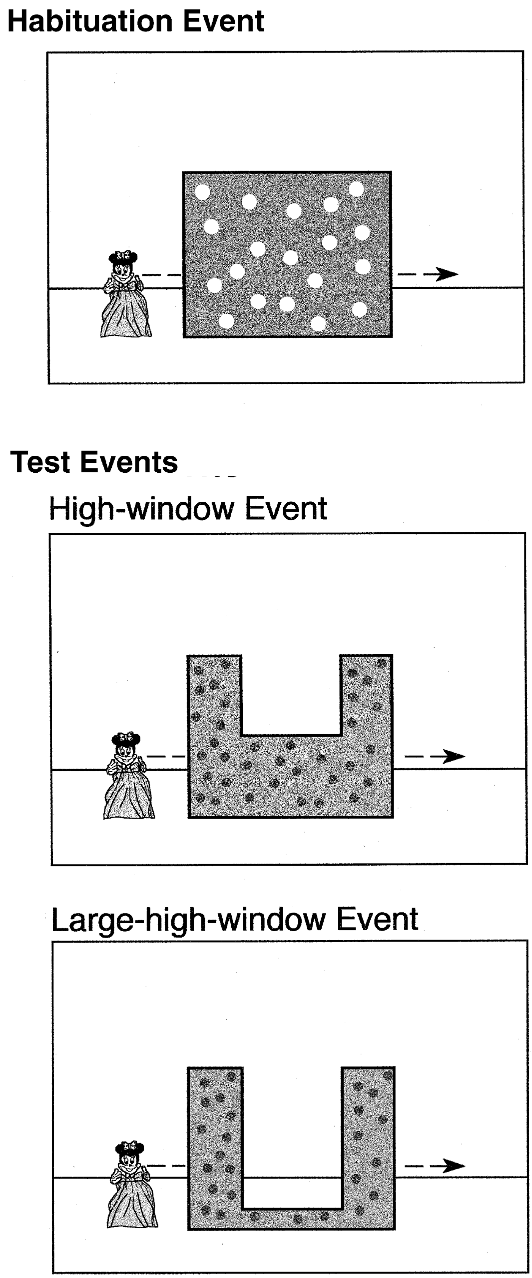

Fig. 12. Schematic drawing of the habituation and test events in Experiment 5.

6.1. Method

Participants. Participants were 12 healthy term infants, 6 male and 6 female, ranging in age from 91 to 99 days ($M = 95.1$ days). An additional 15 infants were tested but eliminated, 7 because of fussiness, 2 because of drowsiness, and 6 because they looked for 90 s on three or more test trials.

Apparatus and events. The apparatus and events used in Experiment 5 were identical to those in Experiment 1 with one exception: The low-window screen was replaced with a large-high-window screen. This screen was similar to the high-window screen, except that the height of the window was increased from 15 to 25.5 cm. The bottom of the window was now 4.5 cm above the apparatus floor; because the mouse was 14 cm tall and was mounted on the carrier 0.5 cm above the floor, its top 10 cm (or 69%) failed to appear in the window. The present violation was somewhat greater than that used by Baillargeon and DeVos (1991): In their experiment, less than the top half (11.5/27.5 cm or 42%) of the tall carrot failed to become visible when passing behind the screen (see Fig. 3).

Procedure. The procedure used in Experiment 5 was identical to that in Experiment 1. Five infants failed to satisfy the habituation criterion within 9 trials; the remaining 7 infants took an average of 6.4 trials to reach the criterion. Interobserver agreement during the test trials was measured for all of the infants and averaged 94.2% per trial per infant. Based on the primary observer's responses, 8 of the 48 test trials (12 infants $\times$ 4 test trials) ended because the infant had looked at the event for 90 s; the average looking time recorded by the secondary observer on these trials was 89.1 s. The secondary observer agreed that the infant was not looking at the end of 37 of the 40 trials that ended with a 2-s look away; the average look away registered by the secondary observer at the end of these trials was 1.9 s. Preliminary analyses revealed no significant interaction between sex and event, $F(1, 10) = 2.05$, $p > .05$; the data were therefore collapsed across sex in subsequent analyses.

6.2. Results

Fig. 13 shows the mean looking times of the infants in Experiment 5 at the large-high- and high-window test events; for ease of comparison, the mean looking times of the 3-month-old infants in Experiment 1 at the low- and high-window test events are also included. It can be seen that the infants in Experiment 5, unlike those in Experiment 1, tended to look equally at the test events they were shown.

The infants' looking times at the test events were averaged and analyzed by means of a 2×2 ANOVA, with order (large-high- or high-window event first) as a between-subjects factor and with event (large-high- or high-window) as a within-subject factor. The main effect of event was not significant,

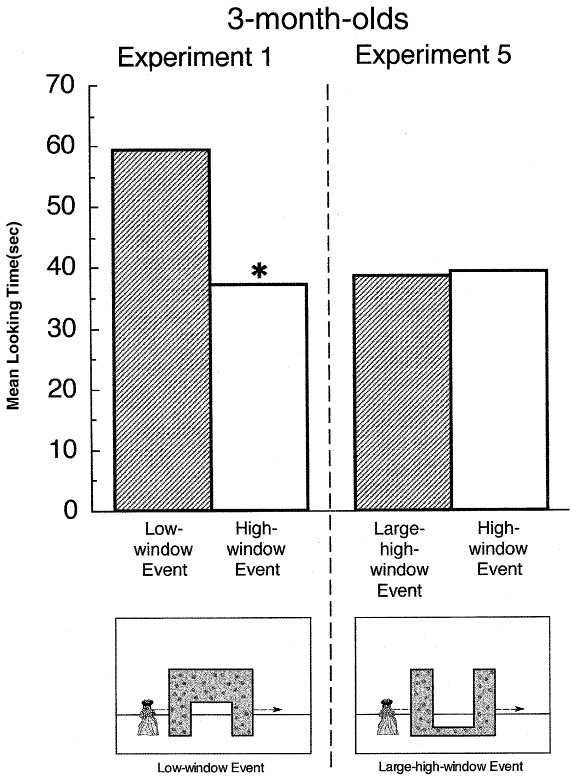

Fig. 13. Mean looking times of the 3-month-olds in Experiment 5 at the large high- and high-window test events. For comparison purposes, this figure also shows the mean looking times of the 3-month-olds in Experiment 1 at the low- and high-window test events.

$F(1, 10) = 0.02$, indicating that the infants did not differ reliably in their looking times at the large-high- ($M = 38.7$, $SD = 21.2$) and high-window ($M = 39.4$, $SD = 21.1$) events. No other effect was significant. Examination of the individual infants' mean looking times yielded similar findings (see Fig. 14): Only 7 of the 12 infants looked longer at the large-high- than at the high-window event, Wilcoxon $T = 42.5$, $p > .05$.

Comparison of Experiments 1 and 5. The responses of the 3-month-old infants in Experiments 1 and 5 were compared by means of a $2 \times 2 \times 2$ ANOVA, with experiment (1 or 5) and order (large-high-/low- or high-window event first) as between-subject factors and with event (large-high-/low- or high-window) as a within-subject factor. The main effect of event was significant, $F(1, 18) = 9.18$, $p < .01$, as was the experiment $\times$ event interaction, $F(1, 18) = 10.25$, $p < .005$. Planned comparisons confirmed that the 3-month-old infants in Experiment 1 looked reliably longer at the low- than at the high-window event, $F(1, 18) = 17.80$, $p < .001$, but that

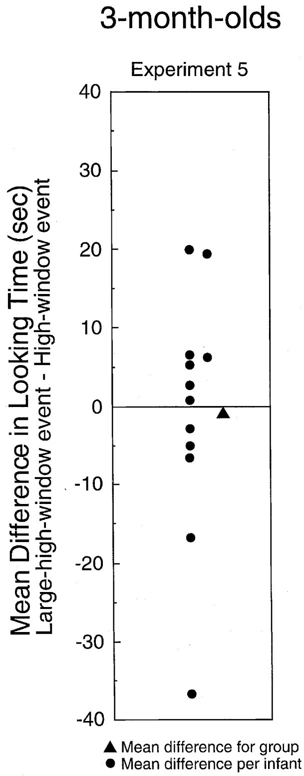

Fig. 14. Difference in the mean looking times of the 3-month-olds in Experiment 5 at the large high- and high-window test events. Each dot represents an individual infant.

those in Experiment 5 tended to look equally at the large-high- and high-window events, $F(1, 18) = 0.02$.

6.3. Discussion

The infants in Experiment 5 tended to look equally at the large-high- and high-window test events. These results provided little support for the notion that 3-month-old infants can attend to discontinuities in both the upper and lower edges of occluders but reveal the former ability only under optimal test conditions. Like the 3-month-old infants in the carrot experiment of Baillargeon and DeVos (1991), the infants in the present experiment failed to show surprise at a violation involving an upper discontinuity. The present results thus strengthened the conclusion that 3-month-old infants (1) believe that an object continues to exist when behind an occluder, (2) realize that the object cannot disappear at one edge of the occluder and reappear at the other edge without traveling the distance behind the occluder, but (3) do not yet appreciate that the height of the object relative to that of the occluder determines whether the object should remain continuously hidden or become temporarily visible when passing behind the occluder.

Why do infants, in learning about occlusion events, attend first to the lower and only after some time to the upper edges of occluders? Our approach to this question reflects our general model of infants' acquisition of their physical knowledge (for a recent review, see Baillargeon, in press). According to this model, infants "sort" events into distinct categories, such as occlusion and containment, and learn separately how each category operates. Specifically, for each event category, infants first form an initial concept centered on a primitive, all-or-none distinction; with further experience, infants identify a sequence of variables—some discrete and others continuous—that elaborates this initial concept, resulting in increasingly accurate predictions and interpretations over time. In the model, variables are akin to contrastive condition–outcome rules: For a given set of contrastive outcomes, a rule specifies what condition produces what outcome. For example, in the case of the variable discontinuities in the lowers edges of occluders, the rule would be as follows: "If an object moves behind an occluder with an opening extending from its lower edge, the object becomes visible when behind the opening; if an object moves behind an occluder with no opening extending from its lower edge, the object remains hidden."

How do infants add new variables to their knowledge of an event category? We suspect that what triggers the identification of a new variable is exposure to contrastive outcomes not predicted by infants' current knowledge of the event category. Upon noticing these outcomes, infants begin to search for the conditions that map onto them; the identification of these condition–outcome relations signals the identification of a new variable. According to this account (for a fuller discussion, see Baillargeon, in press), at least two distinct factors can hinder infants' identification of a variable. First, if infants are not exposed to the contrastive outcomes for a variable, they should have no reason to seek out the conditions responsible for these outcomes. Second, if infants are exposed to and register the contrastive outcomes for a variable, but have difficulty uncovering the conditions responsible for these outcomes, they should again be unable to identify the variable.

Armed with these general speculations, let us now return to the issue of why infants, in learning about occlusion events, attend first to the presence of discontinuities in the lower edges of occluders and only later to the relative heights of objects and occluders (for ease of communication, we refer to these variables in the following discussion as the lower discontinuity and height variables). A first possibility—in line with the first factor listed above—is that infants are more often exposed to contrastive outcomes for the lower discontinuity than for the height variable, so that the learning process is triggered earlier for the first than for the second variable. According to this possibility, infants would have more opportunities to observe that objects sometimes become visible at the lower edges of occluders and sometimes do not than to observe that objects sometimes protrude above occluders and sometimes do not.

A second possibility—in line with the second factor above—is that infants have more difficulty uncovering the conditions that map onto the contrastive outcomes for the lower discontinuity than for the height variable. There are at least two reasons why this might be the case. One, already mentioned in Section 1, has to do with the complexity of each variable. In order to identify the lower discontinuity variable, infants do not need to encode information about the objects that move behind the occluders; they only need to encode whether the occluders have continuous or discontinuous lower edges and whether the objects remain hidden or become visible when behind them (e.g., "If the occluder has an opening extending from its lower edge, the object becomes visible when passing behind this opening; if not, it does not"). In the case of the height variable, however, the relevant conditions are somewhat more complex: Infants must encode information about *both* the objects and occluders. Specifically, infants must compare the heights of the objects and occluders and relate the output of this comparison to the observed outcome (e.g., "If the object is taller than the occluder, it becomes visible above the occluder; if not, it does not"). It seems reasonable that variables that require processing more or more complex information would be harder to identify and hence would be learned later.

Another reason why it may be easier for infants to uncover the conditions involved in the lower discontinuity than the height variable has to do with the fact that lower discontinuity is a discrete and height a continuous variable. Prior research (e.g., Baillargeon, 1994a, 1995) indicates that when infants begin to reason about a new continuous variable in an event category, they can do so qualitatively but not quantitatively: They cannot encode and remember information about absolute amounts. To encode qualitative information about the heights of objects and occluders, infants must compare them as they stand side by side. This means that infants should be able to gather information about the height variable in situations involving *lateral* occlusions (e.g., a cup that is pushed behind a teapot), but not *vertical* occlusions (e.g., an apple that is lowered behind a mug). In the case of the lower discontinuity variable, in contrast, infants should have the same opportunity to collect relevant information with lateral or vertical occlusions: Either way, infants should be able to note that objects remain hidden when behind occluders with continuous but not discontinuous lower edges.

In the preceding discussion, we have outlined several possible reasons why infants identify first lower discontinuity and then height as occlusion variables. Further research is needed to specify all of the different factors that might contribute to this development.

7. Experiment 6

The positive responses of the 3-month-old infants in Experiment 1 contrasted not only with the negative responses obtained with 2.5- and 3-month-old infants in earlier experiments (Aguiar & Baillargeon, 1999; Baillargeon & DeVos, 1991), but also with the negative responses of the 3.5-month-old infants in Experiments 1 and 1A. As suggested earlier, our interpretation of this discrepancy was that, unlike these older infants, the younger infants were not able to spontaneously generate a two-mouse explanation for the low-window test event. Thus, although both groups of infants detected the violation in the event, only the older infants could make sense of it; the younger infants remained surprised by it throughout the test trials.

Experiment 6 examined whether 3-month-old infants would be able to construct a two-mouse explanation for the low-window test event if shown at the start of each trial that *two* mice were present behind the screen. The infants saw habituation and test events identical to those in Experiment 2 with one exception: Two identical mice were revealed when the screen was lowered at the start of each trial; one mouse stood behind the left and one mouse behind the right edge of the screen (see Fig. 15). As was discussed in Section 1, we knew from previous experiments that even 2.5-month-old infants could take advantage of such a "hint" to make sense of occlusion violations (Aguiar & Baillargeon, 1999). Therefore, we expected that the 3-month-old infants in Experiment 6 would also be able to use the information they were given to explain the apparent violation in the low-window event. We thus predicted that the infants would tend to look equally at the low- and high-window events.

7.1. Method

Participants. Participants were 12 healthy term infants, 5 male and 7 female, ranging in age from 94 to 99 days, ($M = 96.8$ days). An additional 10 infants were tested but eliminated, 7 because of fussiness, 1 because the infant looked for 90 s on three test trials, 1 because of inattentiveness, and 1 because the primary observer had difficulty following the direction of the infant's gaze.

Apparatus and events. The apparatus and events used in Experiment 6 were similar to those in Experiment 2, except that two identical mice were visible behind the screen during the pretrial preceding each trial; one mouse stood behind the left and one mouse behind the right edge of the screen.

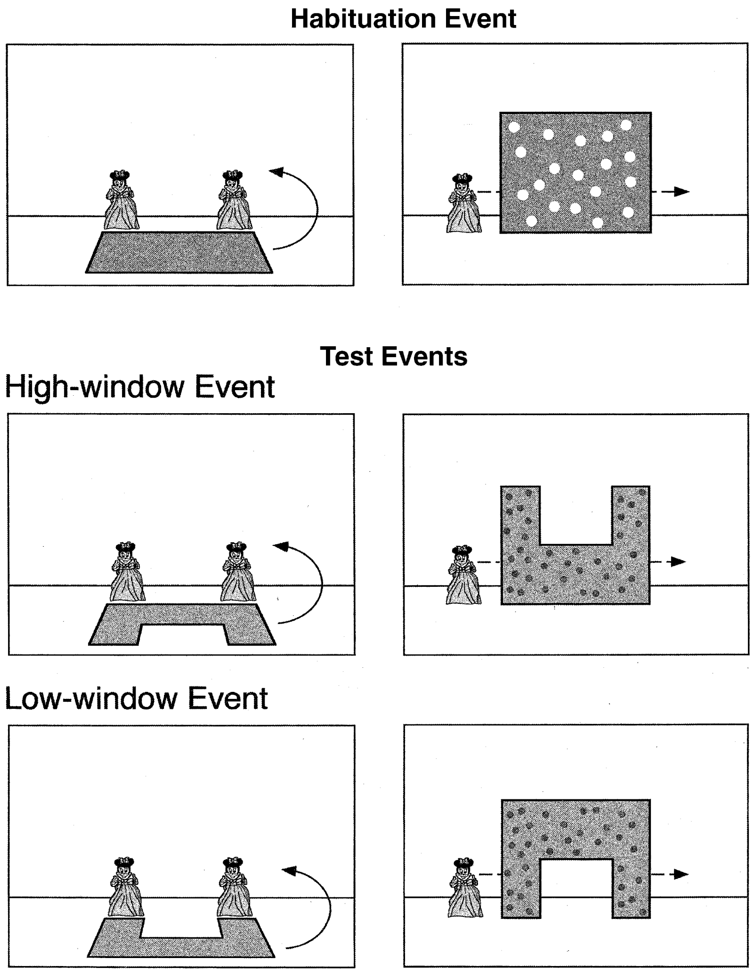

Fig. 15. Schematic drawing of the habituation and test events in Experiment 6.

Procedure. The procedure used in Experiment 6 was identical to that in Experiments 2–4. Six infants failed to satisfy the habituation criterion within 9 trials; the remaining 6 infants took an average of 6.8 trials to reach the criterion. Interobserver agreement during the test trials was measured for all of the infants and averaged 92.2% per trial per infant. Based on the primary observer's responses, 10 of the 48 test trials (12 infants × 4 test trials) ended because the infant had looked at the event for 90 s; the average looking time recorded by the secondary observer on these trials was 89.0 s. The secondary observer agreed that the infant was not looking at the end of 32 of the 38 trials that ended with a 2-s look away; the average look away registered by the secondary observer at the end of these trials was 1.7 s. Preliminary analyses revealed no significant interaction between sex and event, $F(1, 10) = 0.94$; the data were therefore collapsed across sex in subsequent analyses.

7.2. Results

Fig. 16 shows the mean looking times of the infants in Experiment 6 at the low- and high-window test events. It can be seen that the infants looked about equally at the two events.

The infants' looking times at the test events were averaged and analyzed as in Experiment 1A. The main effect of event was not significant, $F(1, 10) = 0.40$, indicating that the infants tended to look equally at the low- ($M = 42.0$, $SD = 14.8$) and high-window ($M = 45.4$, $SD = 22.6$) events. No other effect was significant. Examination of the individual infants' mean looking times yielded similar findings (see Fig. 17): Only 8 of the 12 infants

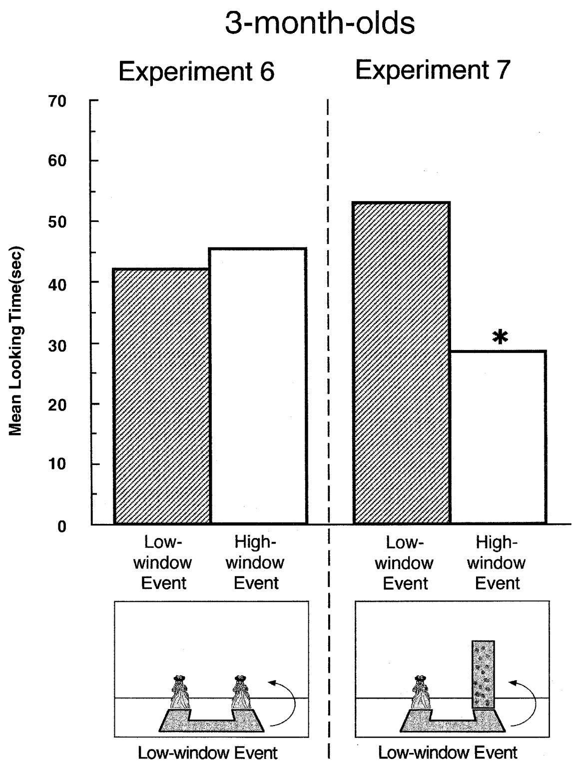

Fig. 16. Mean looking times of the 3-month-olds in Experiments 6 and 7 at the low- and high-window test events.

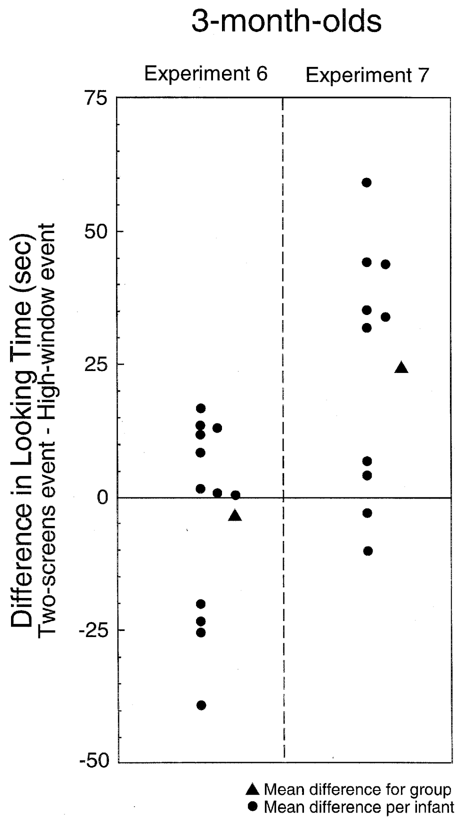

Fig. 17. Difference in the mean looking times of the 3-month-olds in Experiments 6 and 7 at the low- and high-window test events. Each dot represents an individual infant.

in Experiment 6 looked longer at the low- than at the high-window event, Wilcoxon $T = 36$, $p > .05$.

7.3. Discussion

The 3-month-old infants in Experiment 6, unlike those in Experiment 1, tended to look equally at the low- and high-window test events. These results suggested that the infants were able to use the information provided in the pretrials to make sense of the low-window event. Specifically, the infants realized that no mouse appeared in the low window because no mouse in fact traveled from one end of the screen to the other; instead, one mouse traveled to the left and one mouse to the right of the window.

Together, the results of Experiments 1 and 6 suggested that, although the 3-month-old infants were not able to spontaneously generate a two-mouse explanation for the low-window test event, they were able to construct such an explanation when shown that two mice were present in the apparatus. These findings were similar to those obtained with 2.5-month-old infants in the two-screen mouse task (Aguiar & Baillargeon, 1999); recall that the infants were no longer surprised by the two-screen test event when first shown that a mouse stood behind each screen.

Would 3-month-old infants succeed in generating a two-mouse explanation for the low-window test event if given a *weaker* "hint" that a second mouse might be present in the apparatus? To address this question, 3-month-old infants were tested in Experiment 7 with the same procedure as in Experiment 3: The screen was lowered in each pretrial to reveal a mouse and a narrow screen (see Fig. 9). We speculated that, when searching for an explanation for the low-window event, the infants might remember the narrow screen and infer that a second identical mouse must have been hidden behind it. Equal looking times at the low- and high-window events, as in Experiment 6, would suggest that 3-month-old infants are able to spontaneously generate two-object explanations for (at least some) occlusion violations, but require somewhat more contextual support than do 3.5-month-old infants to produce such explanations. On the other hand, reliably longer looking times at the low- than at the high-window event, as in Experiment 1, would suggest that 3-month-old infants cannot spontaneously posit additional hidden objects to make sense of occlusion violations; infants must see two identical objects to construct such explanations.

8. Experiment 7

8.1. Method

Participants. Participants were 10 healthy term infants, 5 male and 5 female, ranging in age from 93 to 100 days ($M = 95.9$ days). An additional 8 infants were tested but eliminated, 7 because of fussiness and 1 because the infant looked for 90 s on three test trials.

Apparatus, events, and procedure. The apparatus, events, and procedure used in Experiment 7 were identical to those in Experiment 3. Five infants failed to satisfy the habituation criterion within 9 trials; the other 5 infants took an average of 7.2 trials to reach the criterion. Interobserver agreement during the test trials was measured for 9 of the 10 infants and averaged 93.8% per test trial per infant. Based on the primary observer's responses, 5 of the 36 test trials (9 infants $\times$ 4 test trials) ended because the infant had looked at the event for 90 s; the average looking time recorded by the secondary observer on these trials was 89.8 s. The secondary observer agreed that the infant was not looking at the end of 28 of the 31 trials that ended with a 2-s look away; the average look away registered by the secondary observer at the end of these trials was 1.8 s. Preliminary analyses revealed no significant interaction between sex and event, $F(1,8) = 1.12$, $p > .05$; the data were therefore collapsed across sex in subsequent analyses.

8.2. Results

Fig. 16 shows the mean looking times of the infants in Experiment 7 at the test events. It can be seen that the infants looked longer at the low- than at the high-window event.

The infants' looking times at the test events were averaged and analyzed as in Experiment 1A. The main effect of event was significant, $F(1,8) = 33.91$, $p < .0005$, indicating that the infants looked reliably longer at the low- ($M = 53.0$, $SD = 25.3$) than at the high-window ($M = 28.4$, $SD = 23.5$) event. Examination of the individual infants' mean looking times yielded similar findings (see Fig. 17): Eight of the 10 infants in Experiment 6 looked longer at the low- than at the high-window event, Wilcoxon $T = 50$, $p < .025$.

The ANOVA also yielded a significant interaction between event and order, $F(1,8) = 19.78$, $p < .0025$. Post hoc comparisons indicated that the infants who saw the low-window event first looked reliably longer at it ($M = 70.1$, $SD = 16.1$) than at the high-window event ($M = 26.7$, $SD = 19.1$), $F(1,8) = 52.74$, $p < .0001$, whereas the infants who saw the high-window event first tended to look equally at the low- ($M = 35.9$, $SD = 21.3$) and high-window ($M = 30.1$, $SD = 29.4$) events, $F(1,8) = 0.95$. Such order effects are not uncommon in violation-of-expectation tasks (e.g., Aguiar & Baillargeon, 1998; Baillargeon, 1986; Baillargeon, DeVos, & Graber, 1989) and are thought to reflect two separate tendencies in infants' responses: A tendency to look longer at whichever event is shown first and a tendency to look longer at the unexpected event. For infants who see the unexpected event first, the two tendencies combine to produce a marked preference for the unexpected event. In contrast, for infants who see the expected event first, the two tendencies cancel each other out, resulting in statistically equal looking times at the unexpected and expected events.

Comparison of Experiments 6 and 7. The test responses of the infants in Experiment 6 (who saw two mice in the pretrials) and in Experiment 7 (who saw a mouse and a narrow screen in the pretrials) were compared by means of a $2 \times 2 \times 2$ ANOVA, with experiment (6 or 7) and order (low-window or high-window event first) as between-subjects factors and with event (low- or high-window) as a within-subject factor (see Figs. 16 and 17). The analysis yielded a significant main effect of event, $F(1,18) = 8.86$, $p < .01$, and a significant interaction between experiment and event, $F(1,18) = 14.35$, $p < .0025$. Planned comparisons confirmed that the infants in Experiment 7 looked reliably longer at the low- than at the high-window event, $F(1,18) = 21.25$, $p < .00025$, but that those in Experiment 6 tended to look equally at the events, $F(1,18) = 0.51$.

The analysis also revealed significant interactions between order and event, $F(1,18) = 9.09$, $p < .01$, and among experiment, order, and event, $F(1,18) = 4.63$, $p < .05$. These order effects were not unexpected, given the reliable order × event interaction found in Experiment 7.

Comparisons of Experiments 3 and 7. A final ANOVA compared the responses of the 3.5-month-old infants in Experiment 3 and of the 3-month-old infants in Experiment 7, who all saw pretrials involving a mouse and a narrow screen (see Figs. 7 and 16). The data were analyzed as in Experiment 1. There was a significant experiment × event interaction, $F(1,16) = 11.32$, $p < .005$, indicating that the 3.5- and 3-month-old infants differed reliably in their responses: Whereas the older infants tended to look equally at the events, $F(1,16) = 1.24$, $p > .05$, the younger infants looked reliably longer at the low-window event, $F(1,16) = 13.28$, $p < .0025$. This last finding thus confirmed the significant age × event interaction observed in Experiment 1.

In addition to the effects noted above, the ANOVA also yielded a significant order × event interaction, $F(1,16) = 7.55$, $p < .025$. This effect does not bear on the present hypotheses and is not discussed further.

Age differences revisited. In all of the research reported in this article, infants who were less than 101 days old were viewed as 3-month-olds and infants ages 101 days and older as 3.5-month-olds. How justified were we in selecting 101 days as the cutoff point for our two age groups? The data presented in Fig. 18 bear on this question. In this analysis, we pooled the data of Experiments 1 and 1A, in which the screen remained upright, and of Experiments 3 and 7, in which the screen was lowered at the start of each

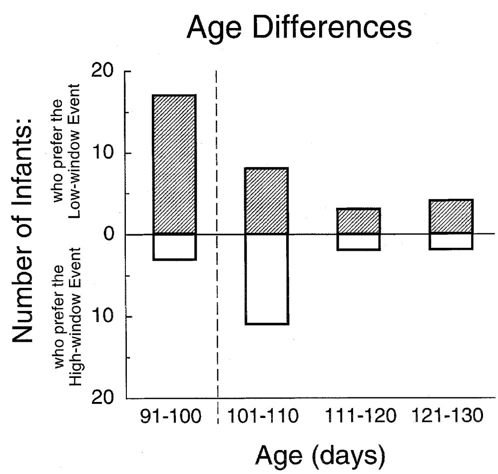

Fig. 18. Number of infants in Experiments 1, 1A, 3, and 7 who preferred the low- or the high-window test event in each 10-day age span from 91 to 130 days.

trial to reveal a mouse and a narrow screen. Both sets of experiments produced identical patterns: The older infants tended to look equally at the low- and high-window test events, suggesting that they were able to infer that a second mouse was present; the younger infants, in contrast, looked reliably longer at the low- than at the high-window event, suggesting that they were *not* able to spontaneously generate a two-mouse explanation for the low-window event.

The infants were divided into separate groups using 10-day spans (e.g., 91–100 days, 101–110 days, and so on). For each span, we entered the number of infants who looked longer at the low- than at the high-window test event and the number of infants who showed the reverse pattern. It can be seen in Fig. 18 that, in the 91- to 100-days span, all but 3 of the 20 infants preferred the low-window event. Beginning at 101 days of age, however, the infants' preference was equally divided between the two events: Fifteen of the 30 infants ages 101 days and older preferred the low-window event, and 15 the high-window event. The difference between the younger and older infants was reliable, $\chi^2(1) = 6.38$, $p < .0125$. Comparison of the 91- to 100- and 101- to 110-days spans alone provides an especially striking contrast, with 17 of the 20 younger infants, but only 8 of the 19 older infants, preferring the low-window event, $\chi^2(1) = 7.79$, $p < .01$.[9]

8.3. Discussion

The infants in Experiment 7, unlike those in Experiment 6, looked reliably longer at the low- than at the high-window test event. This finding suggested that the infants were able to construct a two-mouse explanation for the low-window event *only* when shown two mice in the pretrials. Providing the infants with a "weaker" hint in the shape of a mouse and a narrow screen only slightly wider than the mouse (the screen was 10 cm wide and the mouse 7 cm wide) did not help them infer that a second mouse must have been present behind the narrow screen.

The responses of the 3-month-old infants in Experiment 7 contrasted with those of the 3.5-month-old infants in Experiment 3 and, as such, duplicated the discrepancy observed in Experiments 1 and 1A. Whether the screen was kept upright (Experiments 1 and 1A) or was lowered at the start of each trial to reveal a mouse and a narrow screen (Experiments 3 and 7), the same results were found. In each case, the older infants succeeded in generating a two-mouse explanation for the low-window test event, but the younger infants did not; they remained surprised by the event, resulting in reliably longer looks overall at the low- than at the high-window event.

[9] A regression analysis confirmed that the preference for the low-window test event declined significantly with age (in days), $B = -7.45$, $F(1, 48) = 4.98$, $p < .05$.

Why were the 3-month-old infants unable to produce a two-mouse explanation for the low-window test event? One possibility has to do with the fact that this event involved a violation of very recently acquired knowledge (recall that 2.5-month-old infants do not yet detect the violation in the low-window event; Aguiar & Baillargeon, 1999). Perhaps the 3.5-month-old infants were successful due to simply having lived longer with the knowledge that objects typically become visible when passing behind occluders with discontinuities in their lower edges. When confronted with the low-window event, the infants were more practiced at making a prediction and hence swifter at detecting the violation. As a result, the infants had greater opportunity to ponder the violation and find an explanation for it. In contrast, the 3-month-old infants, who had just learned about discontinuities in the lower edges of occluders, found the task of making a prediction more challenging, leaving them with less time to generate a solution.

Some findings from the present research are consistent with the preceding hypothesis. These findings involve a comparison of the responses of the 3.5- and 3-month-old infants who looked reliably longer overall at the low- than at the high-window test event. The 3.5-month-old infants came from Experiment 2 (in which the screen was lowered during the pretrials to reveal a single mouse) and Experiment 4 (in which the screen was lowered to reveal a mouse and a narrow screen with an empty low window); these were the infants in the preference condition in the additional data analyses reported following Experiment 4. The 3-month-old infants came from Experiment 1 (in which the screen remained upright) and Experiment 7 (in which the screen was lowered to reveal a mouse and a narrow screen with no window). The comparison focused on the infants' mean preference for the low-window test event as measured (1) in their initial looks during the first test trial, (2) in the first test pair, and (3) in the second test pair. In each case, the mean preference was computed by subtracting the mean looking time at the high-window event from the mean looking time at the low-window event. The 3.5-month-old infants' mean preference for the low-window event decreased from 32.3 s in their first look during the first test trial to 29.5 s in the first test pair and to 17.1 s in the second test pair. In contrast, the 3-month-old infants' preference increased from 8.1 s in their first look, to 15.9 s in the first test pair, and to 30.8 s in the second test pair.[10] Thus, the older infants showed an immediate marked preference for the low-window event, which decreased gradually as the test trials progressed. In contrast, the younger infants' preference for the low-window event was initially modest and

[10] The 3-month-old infants' first looks were calculated in the same manner as those of the 3.5-month-old infants (for details, see the additional analyses following Experiment 4). Of the 20 3-month-old infants in Experiments 1 and 7, 14 met the criteria for inclusion; 9 saw the low-window test event ($M = 46.4$, $SD = 33.7$), and 5 saw the high-window test event ($M = 38.3$, $SD = 42.3$).

increased gradually across the test trials. These data support the notion that, whereas the older infants swiftly detected the violation in the low-window event, the younger infants were slower at doing so, leaving them with less time (or opportunity) to ponder the violation.

Of course, other accounts are possible for the 3-month-old infants' failure to spontaneously generate a two-mouse explanation for the low-window test event. For example, it could be that, due to some cognitive immaturity, infants this age still lack the ability to *posit* occluded objects. According to this hypothesis, 3-month-old infants could *represent* the existence of objects they have observed becoming occluded, but they could not *infer* the existence of additional occluded objects. Infants would thus be able to make sense of the low-window event only when shown two identical mice simultaneously.

One way to decide between the two hypotheses advanced above might be to test a prediction derived from the first hypothesis. If the key factor in infants' offering two-object explanations for occlusion violations is their knowledge of the relevant rule and ease or practice in making appropriate predictions, then 3-month-old infants might succeed at generating a two-mouse explanation when tested, not with the low-window test event used in the present experiments, but rather with the two-screen test event used in our previous research with 2.5-month-old infants (Aguiar & Baillargeon, 1999). Presumably, 3-month-old infants would readily detect the violation in the two-screen event, giving them greater opportunity to produce an explanation for it. On the other hand, if the key factor in infants' offering two-object explanations for occlusion violations is the cognitive maturation that makes it possible for them to infer the existence of additional occluded objects, then 3-month-old infants should be equally unable to generate a two-mouse explanation for the two-screen or the low-window event.

9. General discussion

The present results reveal two separate developments in young infants' reasoning about occluded objects. The *first* concerns infants' knowledge of the conditions under which objects should and should not be occluded. The results of Experiments 1, 5, and 7, together with prior results by Aguiar and Baillargeon (1999) and Baillargeon and DeVos (1991), make clear that 3-month-old infants have progressed beyond their initial concept of when objects should be occluded, even though they have not yet reached the same level of knowledge as 3.5-month-old infants. Specifically, whereas 2.5-month-old infants expect any object to be hidden when behind any occluder (Aguiar & Baillargeon, 1999), 3-month-old infants have come to realize that objects typically become temporarily visible when passing behind occluders with discontinuities in their lower edges (Experiments 1 and 7). However, infants are still unable to reason about the heights of objects and occluders

(Experiment 5 and Baillargeon & DeVos, 1991): They expect both tall and short objects to remain hidden when passing behind short occluders. It is not until infants are about 3.5 months of age that they begin to attend to height information and expect short but not tall objects to be hidden behind short occluders (Baillargeon & DeVos, 1991; Hespos & Baillargeon, 2001a).

The *second* development revealed by the present research concerns infants' ability to generate two-object explanations for violations of their occlusion knowledge. Only the 3.5-month-old infants were successful at inferring that two identical mice were involved in the low-window test event. These infants showed no reliable overall preference for this event (1) when the screen was kept upright, leaving open the possibility that two mice were present (Experiments 1 and 1A), or (2) when the screen was lowered at the start of each trial to reveal a mouse and a windowless narrow screen that could hide a second mouse (Experiment 3). The infants showed a reliable overall preference for the low-window event only when they were given information contradicting a two-mouse explanation. This occurred when the screen was lowered at the start of each trial to reveal (1) a single mouse (Experiment 2) or (2) a mouse and a narrow screen with a visibly empty low window (Experiment 4). Together, these results indicate that the infants consistently produced a two-mouse explanation for the low-window event, unless given information to the contrary. These results confirm previous findings that infants ages 4 months and older can produce two-object explanations to make sense of (at least some) violations of their occlusion knowledge (Baillargeon, 1994b; Spelke & Kestenbaum, 1986; Spelke et al., 1995a).

In contrast to the 3.5-month-old infants, the 3-month-old infants in the present research looked reliably longer at the low- than at the high-window test event (1) when the screen was kept upright (Experiment 1) and (2) when the screen was lowered to reveal a mouse and a windowless narrow screen (Experiment 7). The infants looked equally at the two test events only when shown two identical mice at the start of each trial (Experiment 6). Unlike the older infants, the younger infants were thus unable to posit a second mouse to make sense of the low-window event; however, they could use the information that two mice were present to construct a satisfactory explanation for the low-window event. This last result is consistent with prior evidence that 2.5-month-old infants can generate two-object explanations for violations of their occlusion knowledge when shown the two objects at the start of each trial (Aguiar & Baillargeon, 1999).

9.1. A model of young infants' responses to occlusion events

Based on the present results and related prior results with young infants (e.g., Aguiar & Baillargeon, 1999; Baillargeon, 1987, 1994b; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987; Hespos & Baillargeon, 2001a,b; Spelke & Kestenbaum, 1986; Spelke et al., 1992, Spelke, Phillips,

& Woodward, 1995b; Wilcox et al., 1996), we believe that a model of infants' responses to occluded objects must include at least three components: Their knowledge of when objects should and should not be occluded, their ability to posit occluded objects to make sense of events that violate this occlusion knowledge, and their belief that objects exist continuously in time and space when behind occluders.[11] Each component is discussed briefly in turn.

Knowledge of occlusion. Infants' knowledge of when objects should and should not be occluded changes rapidly between 2.5 and 3.5 months of age[12] and develops according to the same general pattern that has been identified for other event categories: Infants begin with a primitive all-or-none concept that is progressively elaborated through the addition of various discrete and continuous variables (for reviews, see Baillargeon, 1994a, 1995, 1998, in press).

This developmental pattern suggests many questions for future research. In particular, what is the precise nature of the initial concepts and variables infants identify for each event category? Earlier (under Section 6.3) we suggested that initial concepts and variables are akin to *contrastive condition–outcome rules*: They specify what outcome is to be expected when a specific condition is met and what distinct outcome is to be expected when a different condition is met. Thus, 2.5-month-old infants expect an object to be hidden when behind an occluder, and to be visible when not; 3-month-old infants expect an object to remain hidden when passing behind an occluder with a continuous lower edge, and to become visible when passing behind an occluder with a discontinuous lower edge; and so on.

However, an alternative account could be offered for the present results and for those of Aguiar and Baillargeon (1999) and Baillargeon and DeVos (1991) that does *not* share the assumption that infants' initial concept and variables are akin to contrastive rules. To illustrate, consider the results obtained with the 3-month-old infants in Experiments 1 and 5. One could suggest that the infants (1) were surprised that the mouse failed to appear in the screen's low window (Experiment 1) because they had a clear expectation that objects should be visible when passing behind occluders with discontinuous lower edges and (2) were not surprised that the mouse failed to appear in the screen's large high window (Experiment 7) because they had *no* clear expectation as to whether objects should remain hidden or become visible

[11] A fourth and equally important component of the model, having to do with infants' ability to *act* on their representations of occluded objects to retrieve them, cannot be considered here due to space limitations (for an in-depth discussion of this fourth component, see Aguiar, Kolstad, Baillargeon, & Menard, 2002).

[12] The development of infants' knowledge about occlusion obviously continues beyond this age period (e.g., Arterberry, 1997; Wilcox, 1999; Wilcox & Baillargeon, 1998a); we simply focus here on the beginnings of this development.

when passing behind occluders with continuous lower edges. This interpretation differs from the one proposed earlier in that it assumes that infants acquire *single condition–outcome rules*. When an object passes behind an occluder with a discontinuous lower edge, infants expect the object to become visible; when an object passes behind an occluder with a continuous lower edge, however, infants do not know what outcome to expect.

One way to decide whether infants acquire contrastive or single condition–outcome rules about occlusion events is to test, at each stage of development, whether infants hold expectations not only for when objects *should* become visible when passing behind occluders, but also for when they should *not*. Luo (2000) recently conducted a series of experiments to perform such tests. For example, in one experiment, 3-month-old infants saw a cylinder move back and forth behind an occluder. This occluder consisted of two screens that were connected at the top (top event) or at the bottom (bottom event) by a short strip (the cylinder was as tall as the screens so that the proportion of the cylinder that should appear between the screens was identical in the two events). In each test event, the cylinder either failed to appear (disappear condition) or appeared as it should (appear condition) between the two screens.

Predictions were as follows. According to the contrastive-rules interpretation, 3-month-old infants expect objects to become visible when passing behind occluders with discontinuous lower edges and to remain hidden when passing behind occluders with continuous lower edges. Therefore, the infants in the disappear condition should look reliably longer at the top than at the bottom event, and the infants in the appear condition should show the reverse looking pattern. On the other hand, according to the single-rules interpretation, 3-month-old infants expect objects to become visible when passing behind occluders with discontinuous lower edges, but hold no clear expectations about objects passing behind occluders with continuous lower edges. This interpretation predicts that the infants in the disappear condition should again look reliably longer at the top than at the bottom event, but that the infants in the appear condition should tend to look equally at the two events.

The data supported the contrastive-rules interpretation: The infants in the disappear condition were surprised that the cylinder did not appear between the two screens that were connected at the top, and the infants in the appear condition were surprised that the cylinder did appear between the two screens that were connected at the bottom.

These results (as well as parallel results with 2.5-month-old infants; Luo, 2000) provide strong evidence that infants' variables are akin to contrastive condition–outcome rules. An alternative way of describing these rules is in terms of dimensions and values. For example, one could say that at about 3 months of age, infants begin to consider the dimension "lower edge of occluder" when predicting occlusion outcomes; this dimension has two values, "lower edge is continuous" and "lower edge is discontinuous." Each value is associated with a distinct outcome: "object will remain hidden" in the case of the first value, and "object will become visible" in the case of the second. Infants cannot predict an outcome for one value on a dimension and remain agnostic about another (as would be the case in the single condition–outcome rules scenario).[13]

Luo's (2000) findings, together with additional findings cited earlier (e.g., Baillargeon, 1994a, 1995, 1998, in press), are helping us gain insights into the nature of infants' physical knowledge. They suggest that, when learning about an event category (e.g., occlusion events), infants identify individual facets of the category (e.g., should objects be hidden or visible when behind occluders, or how soon should objects reappear from behind occluders). For each facet, infants identify variables that map out contrastive condition–outcome relations (e.g., "an object will remain hidden when passing behind an occluder with a continuous lower edge and will become visible when passing behind an occluder with a discontinuous lower edge"). In time, infants may add new facets to their knowledge of an event category, and they may add new variables to an already existing facet. But any variable for any facet will consist of contrastive condition–outcome rules.

The preceding speculations give rise to many fascinating questions about the nature of the processes that make it possible for infants to form event categories, isolate individual facets within each category, identify contrastive condition–outcome rules about how each facet operates, and continually elaborate these rules in light of experience. Although much has been learned about infants' approach to the physical world, clearly much more remains to be uncovered.

Ability to posit additional occluded objects. In addition to gradually learning when objects should and should not be occluded, infants also learn how to make sense of events that appear to violate their developing occlusion knowledge. When an object fails to appear between two screens, 2.5-month-old infants are unable to infer that two identical objects must be

[13] It is interesting, in the present context, to consider how infants reason about height in occlusion events. Do infants simply expect an object that is taller but not shorter than an occluder to protrude above it? Or do infants form more precise predictions and expect an object that is taller than an occluder by a given amount (e.g., 10 cm) to protrude above the occluder by the same amount? In the former case, the variable height would consist of a discrete function with two conditions (shorter or taller than occluder); in the latter case, the variable height would consist of a continuous function with multiple conditions corresponding to perceptually distinct amounts (e.g., 10 or 20 cm taller than the occluder). Experiments are planned to test which of these two possibilities best describes infants' reasoning about height in occlusion events. Note, however, that with either possibility, the variable height maps contrastive condition–outcome relations, with different conditions being associated with different outcomes.

involved in the event, one traveling to the left and one to the right of the screens (Aguiar & Baillargeon, 1999). Infants ages 4 months and older, however, seem to readily draw such an inference (Spelke & Kestenbaum, 1986; Spelke et al., 1995a). Similarly, the 3-month-old infants in the present research did not spontaneously guess that two mice must be involved in the low-window test event (Experiments 1 and 7); only the older, 3.5-month-old infants were able to do so (Experiments 1, 1A, and 3).

What developments make it possible for infants to begin to posit additional occluded objects? We have suggested (see Section 8.3) that the discrepant responses of the younger and older infants in the present research could reflect one of two limitations in 3-month-old infants: (1) a problem solving failure stemming from overtaxed cognitive resources (i.e., infants would be slow at making a prediction based on their new occlusion knowledge and hence would have less opportunity to generate a two-object explanation) or (2) an inability to include in their event representations objects they have not directly perceived (i.e., infants would be able to represent objects they have observed becoming occluded, but they would not yet be able to infer the existence of additional occluded objects).

Whichever explanation turns out to be correct (we proposed a possible test in Section 8.3), it should be kept in mind that development does not end there. Infants' being able to posit additional occluded objects in one context does not mean that they will readily do so in all other appropriate contexts. Recall, for example, that both 3.5- and 5.5-month-old infants failed to posit additional objects in the carrot task described in Section 1 (Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987). As was mentioned in Section 1, we suspect that the discrepancy between the responses of the 3.5-month-old infants in the carrot task and in the present tasks (Experiments 1, 1A, and 3) has to do with their assumptions about the object's passage behind the screen. In the present tasks, infants who saw the low-window test event could not easily assume that the object traveled from one end of the screen to the other. In the carrot task, however, infants who saw the tall-carrot test event could far more easily assume that the carrot *did* travel the distance behind the screen; the puzzle that then remained was why the top of the carrot did not appear in the screen window.

The preceding explanation makes a clear prediction: Three-and-a-half- and 5.5-month-old infants in the carrot task should no longer prefer the tall- over the short-carrot test event if tested with a *larger* high window in the tall-carrot test event. The larger the window, the more likely infants should be (1) to realize that the tall carrot does not travel the distance behind the screen and hence (2) to conclude that two identical tall carrots must be involved in the event. This prediction is particularly interesting in that it suggests that making the violation in the tall-carrot test event more obvious (i.e., a greater portion of the tall carrot failing to appear in the window) should have the counterintuitive effect of *eliminating* infants' preference for the event.

As new occlusion situations are explored, investigators will no doubt discover new contexts in which infants of different ages succeed or fail in positing additional objects to make sense of apparent violations of their occlusion knowledge. The study of these various situations should help us identify the different factors that can facilitate or hinder infants' positing of occluded objects.

Beliefs about occluded objects. Following Spelke (1994; Spelke et al., 1992; Spelke, Phillips, & Woodward, 1995b), we believe that, from birth, infants interpret physical events in accord with a few core principles. One such principle is that of continuity, which states that objects exist continuously in time and space; another principle is that of solidity, which states that two objects cannot exist in the same space at the same time.

One of our reasons for suspecting that young infants' event representations are constrained by continuity and solidity principles has to do with the contrast between *event-specific* and *event-general* knowledge. One emerging theme in the research on infants' physical knowledge in recent years has been that the expectations infants acquire are event-specific (for reviews, see Baillargeon, 1995, 1998, in press). As was briefly mentioned earlier, infants seem to form narrow event categories and to learn separately how each operates; variables identified in the context of one category are not generalized to other categories, even when clearly appropriate (e.g., Hespos & Baillargeon, 2001a; Wang & Paterson, 2000). For example, although infants realize at about 3.5 months of age that the height of an object relative to that of an *occluder* determines whether the object can be fully or only partly hidden when behind the occluder (Baillargeon & DeVos, 1991), it is not until infants are about 7.5 months of age that they realize that the height of an object relative to that of a *container* determines whether the object can be fully or only partly hidden when inside the container (Hespos & Baillargeon, 2001a). Furthermore, it is not until later still, at about 12 months of age, that infants realize that the height of an object relative to that of a *cover* (an inverted container) determines whether the object can be fully or only partly hidden inside the cover (Wang & Paterson, 2000; McCall, 2001).

This research contrasts sharply with the evidence that young infants interpret events in accord with continuity and solidity principles. A sensitivity to continuity has been demonstrated in 2.5- to 3.5-month-old infants—the youngest ages tested to date—in the context of occlusion (e.g., Aguiar & Baillargeon, 1999; Spelke et al., 1992; Wilcox et al., 1996), containment (Hespos & Baillargeon, 2001b), and covering (Wang, 2001) events. Similarly, a sensitivity to solidity has been demonstrated in 2.5- to 3.5-month-old infants in the context of containment (Hespos & Baillargeon, 2001b), covering (Wang, 2001), and arrested-motion events (Baillargeon, 1987; Spelke et al., 1992).[14] The evidence that continuity and solidity operate as event-general constraints on even very young infants' event representations—or, to put it another way, the evidence that continuity and solidity behave so differently from the event-specific and incremental knowledge infants acquire about event categories—supports Spelke's (1994) and Spelke et al. (1992, 1995b) proposal that continuity and solidity principles are not acquired at all, but are in fact innate.

It might be objected that there already exists evidence contradicting the proposal that infants are innately predisposed to interpret events in accordance with continuity and solidity principles. For example, what of the finding in Experiment 5 that 3-month-old infants are not surprised when an object fails to appear between two screens connected at the bottom by a short strip (see also Baillargeon & DeVos, 1991; Luo, 2000)? Or the finding that 2.5-month-old infants are not surprised when an object fails to appear between two screens connected at the top by a short strip (Aguiar & Baillargeon, 1999; Luo, 2000)? If infants are innately sensitive to continuity, how could they fail to detect these marked violations (for a discussion of parallel solidity violations, see Baillargeon, in press; Hespos & Baillargeon, 2001b)?

Our interpretation is that, when faced with an occlusion event, infants build an abstract *physical representation* of the event (we are not suggesting that this is the only representation that is built; it seems likely that several representations are built simultaneously, for different purposes). What information infants include in their physical representation of the event depends in part on the knowledge they have acquired about occlusion events. Thus, 3-month-old infants, who have not yet identified height as an occlusion variable, are unlikely to include information about the relative heights of the object and occluder when representing the event. Because the continuity principle operates at the level of infants' physical representations, *it can operate only on the information available in the representations—it cannot operate on information that has not been included.* If all that an infant represents at 3 months of age is "object passing, out of view, behind occluder with continuous lower edge," the event will be deemed consistent with the infant's continuity constraint and (limited) knowledge of occlusion. But if the object is taller than the occluder, and yet does not protrude above it, then infants will fail to detect what is in fact a continuity violation (for further discussion, see Baillargeon, in press; Hespos & Baillargeon, 2001b).

[14] In a collision event, an object approaches and hits another object, which may or may not be displaced; in an arrested-motion event, an object approaches a surface such as a wall, floor, or large table top and stops against it. Of course, the two events may be combined, as when an object approaches and hits an object resting against a surface; the first object then stops against the second one, which becomes, in essence, an extension of the surface (e.g., Baillargeon et al., 1985; Baillargeon, 1987, 1991).

A final note. We have suggested that, when young infants see an object moving back an forth behind an occluder, their continuity principle (Spelke, 1994; Spelke et al., 1992, 1995b) leads them to view the object as existing and moving continuously behind the occluder. However, infants still have a great deal to learn about the event. They must learn to predict whether the object should be fully and continuously hidden when behind the occluder, how long it should remain behind the occluder, and so on. Our results suggest that infants acquire their occlusion knowledge gradually, variable by variable, just as they do their knowledge about other physical events. Infants also learn to cope with apparent violations of their occlusion knowledge. For example, infants come to realize that, in certain occlusion situations, an object failing to appear where it should have (as in the present experiments) can be due to there being two identical objects involved in the events.

9.1.1. Alternative models of young infants' responses to occlusion events

Some current models of young infants' responses to occlusion and other events differ radically from the model described in the previous section. In what follows, we briefly revisit each of the three components of our model, focusing on how it differs from alternative formulations.

Knowledge about occlusion. We have argued that, when learning about occlusion and other physical events, infants identify rules which they continuously revise, resulting in more and more accurate predictions over time.

Our approach differs significantly from another approach that is more or less explicit in some recent work on infant cognition (e.g., Bogartz, Shinskey, & Speaker, 1997; Haith, 1998). In this approach, the process of knowledge acquisition is essentially one of data collection. Bogartz et al. (1997), for example, suggested that infants collect and store "videotapes" of physical events. When faced with a novel event, infants search through their library of videotapes, retrieve the most relevant, and then compare the current and stored events; mismatches engage infants' attention and cause them to update the existing videotape or create a new one.

One of the difficulties with this type of approach[15] is that it cannot easily explain why infants would ever respond with prolonged looking to events that are physically possible (Luo, 2000; see also Kaufman & Baillargeon, 1996). For example, why would 3-month-old infants respond with prolonged looking when an object becomes visible between two screens connected at the bottom by a short strip (Luo, 2000)? Why would infants perceive mismatches where there are none?

[15] Another difficulty with this approach is that it glosses over the complex cognitive apparatus necessary for infants to compare videotapes and determine whether mismatches are present. How do infants know that the physical events they watch in the laboratory are similar to other, superficially very different events they have seen previously and should produce similar outcomes?

To make sense of such results, we must construe the learning process very differently. We must assume that infants, like older learners, formulate rules or hypotheses about physical events and revise and elaborate these hypotheses in light of additional input. In the early stages, when their rules are still primitive, infants may err in two ways: They may fail to view physically impossible events as anomalous or surprising, and they may view physically possible events as surprising.

Scientists have long realized that the physical world is too complex and varied to ever be understood through a simple data collection process. Progress can be achieved only through the formulation of hypotheses and the evaluation of relevant evidence. It seems likely that infants engage in a similar process, though obviously at a more primitive level.

Ability to posit additional occluded objects. It is sometimes assumed that, when they detect that an object has failed to appear in the gap between two screens, infants immediately conclude that two identical objects must be involved in the event (e.g., Scholl & Leslie, 1999). As we have seen, however, infants may succeed in detecting such an occlusion violation and still be unable to infer the presence of an additional object to explain it. The 3-month-old infants in Experiment 1 were surprised when the mouse emerged from behind the screen with a low window without having appeared in the window; but they gave no indication that they concluded that two different mice must be involved in the event. Only the older, 3.5-month-old infants did so. Similarly, the 2.5-month-old infants tested by Aguiar and Baillargeon (1999) were surprised when the mouse emerged from behind the second screen without having appeared between the two screens; but, unlike the 4-month-old infants tested by Spelke and Kestenbaum (1986), they gave no indication that they posited the presence of a second mouse.

In addition to gradually learning when objects should and should not be occluded, infants also gradually learn to make sense of events that appear to violate their occlusion knowledge (recall that even 5.5-month-old infants do not posit the presence of a second object when shown an event such as the tall-carrot test event; Baillargeon & Graber, 1987). How this ability develops remains to be understood; but it is clear that infants' responses to occlusion events cannot be adequately described without taking this development into account.

Beliefs about occluded objects. In the approach presented here, infants do not have to learn that objects continue to exist when behind occluders: A continuity principle constrains from the start their representations of events (Spelke, 1994; Spelke et al., 1992, 1995b). What infants have to learn is everything else: Whether objects should be fully and continuously hidden when behind occluders; how soon objects should reappear from behind occluders; when multiple objects, rather than a single object, are likely to be present behind occluders; and so on.

This approach differs dramatically from recent approaches that assume that young infants either cannot represent occluded objects or can achieve only weak representations of these objects. Four such approaches are discussed briefly below, beginning with the one that differs most from our own.

1. *Perceptual biases*. A number of researchers (e.g., Bogartz et al., 1997; Haith & Benson, 1998) have argued that reports that young infants can represent occluded objects can all be explained more parsimoniously in terms of low-level perceptual biases. For example, Bogartz et al. (1997) suggested that the 3.5-month-old infants in the carrot task (Baillargeon & DeVos, 1991) focused on the carrot's face during the habituation trials and, as they scanned horizontally back and forth, attended only to the portion of the screen that lay at the same height as the face. During the test trials, the infants continued to respond in the same manner. This led them to notice, in the tall-carrot test event, that a window had been created in the upper portion of the screen; in the short-carrot test event, however, the infants did not detect the window's presence because the portion of the screen they attended to lay below the window. The infants' differential test responses thus stemmed from the fact that they detected the introduction of the window in the tall- but not the short-carrot test event. Bogartz et al. further suggested that the control infants who saw two tall and two short carrots on either side of the screen in pretest trials looked equally at the tall- and short-carrot test events because they were led by the pretest trials to focus on the left and right edges of the screen and hence failed to detect the introduction of the window in the test events.

This account could explain the results obtained with the 3.5-month-old infants in Experiments 2 and 4; one could suggest that the infants focused only on the area of the screen corresponding to the mouse's face during the habituation and test trials and thus detected the presence of the window in the low- but not the high-window event. But the same account could not easily explain the results obtained with the 3.5-month-old infants in Experiments 1, 1A, and 3. Why would the infants have responded differently when the screen was kept upright or lowered to reveal a mouse and a narrow screen with an empty low window?

Similar difficulties arise when one considers the results obtained with the 3-month-old infants. Again, one could suggest that the infants in Experiment 1 noticed the low but not the high window. But why would the infants have failed to do the same in Experiment 6, when the screen was lowered to reveal two mice, or in Experiment 5, when the low window was replaced by the large high window? Finally, why would the 3-month-old infants tested by Luo (2000) have shown surprise when the cylinder (which did not have a face) failed to appear between the two screens that were connected at the top but not at the bottom? And why would the infants have shown the reverse response when the cylinder did appear between the screens?

It might be possible to produce local, low-level perceptual explanations for each of these results individually. But such a collection of post hoc, limited-purpose explanations would be unlikely to be more parsimonious than the account offered here (for additional discussion, see Baillargeon, 1999, 2000).

2. *Identity rules*. Meltzoff and Moore (1998) have suggested that young infants cannot represent occluded objects. Rather, infants have available rules for predicting where and when objects that disappear from view should be seen next.

This account could easily encompass our findings on the development of young infants' ability to predict when objects should be occluded. For example, one could suggest that at 3 months of age, infants respond to occlusion events on the basis of the following rules: (1) an object that disappears behind an occluder with a continuous lower edge will next be seen at the occluder's far vertical edge, (2) an object that disappears behind an occluder with a discontinuous lower edge will next be seen at the screen's next vertical edge; and finally, (3) when two identical objects simultaneously disappear behind a screen, no prediction can be made about where they will next appear (e.g., in Experiment 6, when two mice stood behind the screen in the pretrials). As in our model, violations of the rules (either because objects do not appear where they should or appear where they should not) would engage infants' attention, resulting in prolonged looking.

However, the account of Meltzoff and Moore (1998) would have more difficulty explaining our results with 3.5-month-old infants. For example, why would the infants have shown no overall preference (or only a brief, transitory preference) for the low-window test event when the screen was lowered to reveal a mouse and a narrow screen (Experiment 3), but not a mouse and a narrow screen with an empty low window (Experiment 4)? It does not seem plausible that infants would acquire rules for situations in which a narrow screen with or without a window disappears along with an object behind a larger occluder.

Results suggesting that infants are generating two-object explanations for occlusion violations are not the only ones that call into question the approach of Meltzoff and Moore (1998). In some events (e.g., Baillargeon, 1986; Baillargeon & DeVos, 1991), objects always appear where place rules (for stationary objects) and trajectory rules (for moving objects) predict that they should be seen next; and yet infants respond with prolonged looking. For example, in one experiment (Baillargeon, 1986), 6.5-month-old infants saw test events in which a screen was raised to reveal a box behind it; next, the screen was lowered, and a toy car rolled behind one end of the screen and then reappeared from behind the other end. Within each trial, the box was revealed in the same place whenever the screen was raised, and the car followed the same exact trajectory throughout the trial.

And yet the infants looked reliably longer when the box was revealed to rest *on* as opposed to *off* the car's tracks, presumably because they understood that the car could not roll past the screen when the box stood in its path.

3. *Predictions based on visible objects*. Munakata (2001) has proposed that young infants cannot represent occluded objects. Rather, infants possess expectations that enable them to predict, *while objects are still visible*, what will happen when they become occluded. When these predictions are contradicted, infants respond with prolonged looking. Munakata's approach is thus similar to that of Meltzoff and Moore (1998) in that in both approaches (1) infants are said not to represent occluded objects and (2) infants are thought to possess rules that enable them to predict future outcomes. The main difference between the two approaches is that for Meltzoff and Moore infants' rules primarily predict when and where objects that become occluded will next be visible, whereas for Munakata infants' rules serve a wider variety of predictions. To illustrate, in some experiments (Baillargeon, 1987; Baillargeon et al., 1985), young infants were habituated to a screen that rotated back and forth through a 180° arc. Next, a box was placed behind the screen, and the screen either stopped against the box (possible event) or rotated through the space occupied by the box (impossible event). The infants looked reliably longer at the impossible than at the possible event. According to Munakata, the infants predicted, at the start of each event, while the box was still visible, that the screen would stop against the box. When this prediction was violated, the infants responded with prolonged looking.

This approach could explain several of the present results. For example, consider the results obtained with the 3-month-old infants when the screen was kept upright (Experiment 1) or was lowered to reveal a mouse and a narrow screen (Experiment 7). One could suggest that, as the mouse neared the screen, the infants predicted that the mouse would appear in the low window, and they were surprised when this prediction was violated. The negative results of Experiment 5 could also be attributed to the infants not yet holding correct expectations about screens with continuous lower edges.

The results obtained with the 3.5-month-old infants in the present research are more difficult to reconcile with Munakata's (2001) approach, however. Recall that the infants' surprise at the low-window test event rapidly dissipated when the screen was kept upright (Experiments 1 and 1A) or was lowered in the pretrials to reveal a mouse and a narrow screen (Experiment 3). These data suggest that the infants were not limited to making predictions (e.g., "the mouse will appear in the low window") and verifying whether these were subsequently confirmed. The infants were able to posit the existence of an additional mouse behind the screen in Experiments 1 and 1A or behind the narrow screen in Experiment 3. In the latter case, this meant that the infants could access their representation of the occluded narrow screen. Positing additional occluded objects and accessing representations of occluded objects are all achievements that would not be possible in infants limited to formulating predictions about visible objects and their known trajectories.

4. *Fragile representations*. Munakata, McClelland, Johnson, and Siegler (1997) suggested that young infants can represent occluded objects, as evidenced by their responses in violation-of-expectation tasks; however, these representations are weak and fragile and as such considerably different from the stronger or more fully developed representations that underlie older infants' search responses in Piaget's (1954) hallmark test of object permanence.

The 3.5-month-old infants in the present research showed only a brief surprise response at the low-window test event when the screen was kept upright (Experiments 1 and 1A) or was lowered at the start of each trial to reveal a mouse and a windowless narrow screen (Experiment 3). In what sense can we say that these infants' representations were weak or fragile? As the infants puzzled over the mouse's failure to appear in the low window, they eventually arrived at the notion that two mice must be involved in the event. The fact that the infants generated this explanation when the narrow screen was windowless but not otherwise suggests that its representation was sufficiently precise and long-lasting that it could be reliably consulted as the trial proceeded and the infants began their quest for an explanation (recall that the mean initial surprise response of the 3.5-month-old infants in Experiments 1, 1A, and 3 was 39.9 s).

These results suggest that young infants' representations of occluded objects are neither weak nor fragile—though they may well be incomplete initially, especially before infants have learned to attend to variables such as the height and width of objects and occluders. Explanations for young infants' failure to search for hidden objects (e.g., Piaget, 1954), we believe, are more likely to reflect problem solving as opposed to representational limitations (e.g., Aguiar, 1997; Aguiar et al., 2002).

9.2. Concluding remarks

We opened this article with a discussion of Piaget's (1954) seminal work on young infants' responses to occluded objects, and it seems fitting that we end in the same way. Piaget believed that young infants' main developmental task is to realize that objects continue to exist when occluded. The characterization offered here is radically different. We have suggested that, from the start, infants recognize that objects continue to exist when occluded (e.g., Spelke, 1994; Spelke et al., 1992, 1995b) and that their main developmental task is to learn when objects behind occluders should and should not be hidden.

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