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Young infants' reasoning about hidden objects: evidence from violation-of-expectation tasks with test trials only

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Abstract

The present research examined alternative accounts of prior violation-of-expectation (VOE) reports that young infants can represent and reason about hidden objects. According to these accounts, young infants' apparent success in these VOE tasks reflects only novelty and familiarity preferences induced by the habituation or familiarization trials in the tasks. In two experiments, 4-month-old infants were tested in VOE tasks with test trials only. The infants still gave evidence that they could represent and reason about hidden objects: they were surprised, as indicated by greater attention, when a wide object became fully hidden behind a narrow occluder (Experiment 1) or inside a narrow container (Experiment 2). These and control results demonstrate that young infants can succeed at VOE tasks involving hidden objects even when given *no* habituation or familiarization trials. The present research thus provides additional support for the conclusion that young infants possess expectations about hidden objects. Methodological issues concerning the use of habituation or familiarization trials in VOE tasks are also discussed.

Keywords: Infants' physical reasoning; Violation-of-expectation findings; Novelty and familiarity preferences

1. Introduction

Adults' physical world includes both visible and hidden objects. Over the past 20 years, many researchers have examined whether young infants, like adults, can represent hidden

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objects (e.g. Aguiar & Baillargeon, 2002; Baillargeon, Spelke, & Wasserman, 1985; Goubet & Clifton, 1998; Hespos & Baillargeon, 2001a; Hofstadter & Reznick, 1996; Hood & Willatts, 1986; Koechlin, Dehaene, & Mehler, 1998; Lécuyer & Durand, 1998; Leslie, 1995; Luo, Baillargeon, Brueckner, & Munakata, 2003; Newcombe, Huttenlocher, & Learmonth, 1999; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Wang, Baillargeon, & Paterson, in press; Wilcox & Schweinle, 2003; Wynn, 1992). These reports generally make clear that young infants' ability to represent and to reason about hidden objects is in significant ways more limited than that of older children and adults (for recent reviews, see Baillargeon, 2002; Baillargeon & Luo, 2002; Baillargeon & Wang, 2002; Spelke & Hespos, 2001). Nevertheless, the basic ability to represent the continued existence of objects that become hidden appears to already be present by 2.5 months of age (e.g. Aguiar & Baillargeon, 1999; Hespos & Baillargeon, 2001b; Luo & Baillargeon, in press; Spelke et al., 1992; Wang et al., in press; Wilcox, Nadel, & Rosser, 1996).

Most of the reports showing that young infants can represent hidden objects have used the violation-of-expectation (VOE) method. In a typical VOE experiment, infants watch two test events, one consistent (expected event) and one inconsistent (unexpected event) with the expectation examined in the experiment. Prior to the test trials, infants usually receive habituation or familiarization trials[1] to acquaint them with various aspects of the test events. With appropriate controls, evidence that infants look reliably longer at the unexpected than at the expected event is taken to indicate that they (1) possess the expectation under investigation; (2) detect the violation in the unexpected event; and (3) are surprised by this violation. The term surprise is used here simply as a short-hand descriptor, to denote a state of heightened attention or interest caused by an expectation violation.[2]

The VOE reports that infants aged 2.5 months and older can represent hidden objects were among the first to suggest that young infants' cognitive abilities may be richer and more continuous with those of adults than was traditionally believed (e.g. Piaget, 1952, 1954). However, a controversy has recently arisen over these reports: several researchers have suggested that young infants tested with VOE tasks involving hidden objects may look longer at the unexpected than the expected events, not because they possess expectations about such objects, but because the habituation or familiarization events induce in them transient and superficial preferences for the unexpected events (e.g. Bogartz, Shinskey, & Schilling, 2000; Bogartz, Shinskey, & Speaker, 1997; Cashon & Cohen, 2000; Schilling, 2000; Thelen & Smith, 1994). We refer to such accounts as *transient-preference* accounts and describe three such accounts in the following section.

[1] Habituation trials are repeated until the infant either satisfies a habituation criterion (e.g. a 50% or greater decrease in looking time on three consecutive trials, relative to the infant's looking time on the first three trials), or completes a maximum number of habituation trials (e.g. 12 trials). Familiarization trials are administered for a fixed, typically small number of trials (e.g. 4 trials).

[2] Although no systematic evidence has yet been gathered involving facial or behavioral correlates of surprise in VOE tasks, we have occasionally observed such reactions in our laboratory, and for this reason we suspect that there are at times emotional overtones to infants' responses to unexpected events, just as is the case with older children and adults. Until more is known about such correlates, however, we use the term surprise simply to denote the state of increased attention or interest infants experience when confronted by events contrary to their expectations.

1.1. Transient-preference accounts

According to one transient-preference account (Thelen & Smith, 1994), when watching a habituation event in a VOE task, infants build a dynamic representation of the event, or an “attracting trajectory”, that predicts at each point in the event what is likely to happen next. Infants look reliably longer at the unexpected event when it violates the course predicted by the habituation trajectory. To illustrate, infants in one experiment (Baillargeon, 1986; see also Baillargeon & DeVos, 1991) sat facing a screen placed in front of a track; to the left of the track was an inclined ramp. In the habituation event, the screen was raised and lowered, and then a toy car rolled down the ramp and across the track, briefly passing behind the screen. The test events were identical to the habituation event except that a box now stood behind the screen, either on (unexpected event) or behind (expected event) the track; this box was revealed when the screen was raised. The infants looked reliably longer at the unexpected than at the expected event, and Baillargeon took this and control results to suggest that the infants were surprised to see the car roll past the screen when the hidden box blocked its path. Thelen and Smith proposed, in contrast, that when watching the habituation event the infants formed an attracting trajectory involving the *screen* (when it was raised and lowered), the *ramp* (when the car rolled down the ramp), the *left track* (when the car rolled onto the track), the *screen* (when the car rolled behind the screen), and finally the *right track* (when the car rolled past the screen). Both test events deviated from the habituation trajectory when the screen was raised to reveal the box. In the expected event, the box was in a novel location, away from the habituation trajectory; when the screen was lowered, the event continued as predicted. In the unexpected event, however, the box stood closer to the screen and activated the second *screen* location in the habituation trajectory; the beginning of the event was thus “prematurely captured by the end of the habituating trajectory” (Thelen & Smith, 1994, p. 225), so that the event no longer unfolded as predicted.

According to another transient-preference account (Bogartz et al., 1997), when watching the habituation event in a VOE task, infants often attend to only a portion of the event. This limited processing may lead them to detect the presence of novel elements in the unexpected but not the expected event. To illustrate, infants in one experiment (Baillargeon & Graber, 1987; see also Baillargeon & DeVos, 1991) were habituated to a tall or a short toy rabbit sliding back and forth behind a screen. Next, a window was created in the screen’s upper half, and the infants again saw the tall (unexpected event) and the short (expected event) rabbit slide back and forth behind the screen. The tall rabbit should have appeared in the window, but did not do so. The infants looked reliably longer at the unexpected than at the expected event, and Baillargeon and Graber took this and control results to suggest that the infants were surprised that the tall rabbit failed to appear in the window. Bogartz et al. proposed a very different account: they suggested that the infants focused on the rabbit’s face in each habituation event 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 test, the infants continued to scan the events in the same manner; as a result, they detected the novel window in the unexpected but not the expected event. The infants thus looked reliably longer at the unexpected event simply because they noticed the presence of the window in this event.

Yet another transient-preference account (e.g. Bogartz et al., 2000; Cashon & Cohen, 2000; Roder, Bushnell, & Sasseville, 2000; Schilling, 2000) focuses on VOE tasks in which the unexpected event is perceptually more similar to the habituation event than is the expected event. According to this account, infants may often be unable to fully encode the habituation event prior to the test trials. As a result, infants look reliably longer at the unexpected event so as to continue their processing of the event.[3] To illustrate, infants in a series of experiments (Baillargeon, 1987; Baillargeon et al., 1985) were habituated to a screen that rotated back and forth through a 180° arc. Next, a box was placed behind the screen, and the infants saw two test events. In one, the screen rotated until it reached the hidden box (expected event); in the other event, the screen rotated through a full 180° arc, as though the box was no longer present (unexpected event). The infants looked reliably longer at the unexpected than at the expected event, and Baillargeon and her colleagues took this and control results to suggest that the infants were surprised that the screen did not stop against the hidden box. Proponents of this third transient-preference account, in contrast, suggested that the infants displayed a familiarity preference: they were not able to completely encode the 180° rotation in the course of the habituation trials and so they preferred the unexpected event because it too involved a 180° rotation, which allowed them to continue the processing begun in the habituation trials.

1.2. The present research

The transient-preference accounts described in the previous section have been criticized on various grounds (e.g. Aguiar & Baillargeon, 2002; Aslin, 2000; Baillargeon,

[3] The notion that familiarity preferences might contribute to infants' responses to unexpected and expected test events was derived from prior demonstrations that infants presented with static visual stimuli (e.g. objects or color slides of objects) often show a familiarity preference under shorter familiarization conditions, and a novelty preference under longer familiarization conditions (e.g. Hunter & Ames, 1988; Hunter et al., 1982, 1983; Roder et al., 2000; Rose et al., 1982; Wagner & Sakovits, 1986). The amount of familiarization needed to elicit a novelty as opposed to a familiarity preference typically varies with age and task difficulty (e.g. the number of objects presented). To illustrate, Rose et al. (1982) presented 3.5-month-old infants with an object until they accumulated 5, 10, 15, 20, or 30 s of looking at the object. Next, the object was paired with another object of a different shape. The infants showed a reliable preference for the familiar object after 10 s of familiarization, and a reliable preference for the novel object after 30 s. Older, 6.5-month-old infants tested with the same objects showed a reliable familiarity preference after 5 s of familiarization, and a reliable novelty preference after 15 s. The authors took their results to suggest that "as infants begin to process a stimulus, they prefer to look at that which is familiar; once processing is more advanced, their preference shifts to that which is novel" (p. 711). It seems plausible that infants whose processing of an object is interrupted would be motivated to return to the object, so as to complete their processing (Hunter & Ames, 1988). For infants to recognize and categorize objects, adequate representations must be stored; infants who continually flitted from object to object would have difficulty forming such representations. As Hunter et al. (1982) charmingly put it, "infant exploratory behavior is orderly… they give priority to understanding what they have begun to know and to consolidating information they are in the process of acquiring before moving on to make new discoveries" (p. 528). However, it is not clear whether the same pattern should be expected in VOE experiments, where infants' task is *not* that of recognizing and categorizing events, but rather that of predicting and interpreting the events' outcomes. Would we expect older children and adults attending a magic show to prefer non-magical events under brief exposure conditions, and magical events under longer exposure conditions? Or would we expect older children and adults to consistently attend longer to the events that violate their expectations, as long as they see enough of the events to detect the violations? We return to this issue in the General Discussion.

1999, 2000; Munakata, 2000; we consider some of these criticisms in the General Discussion). Nevertheless, these accounts all reflect the same pervasive concern, that young infants' apparent success in VOE tasks involving hidden objects may reflect only novelty or familiarity preferences induced by subtle interactions between the habituation or familiarization and the test trials. It is this general concern that we wished to address here. According to transient-preference accounts, young infants should fail at VOE tasks involving hidden objects when given *no* habituation or familiarization trials. Without such trials, infants could have no opportunity to form transient preferences, and they should therefore tend to look equally at the unexpected and expected events. Experiment 1 tested this prediction: it examined young infants' ability to represent and reason about a hidden object in a VOE task with no habituation or familiarization trials—only test trials.

Positive results have already been obtained in a test-only VOE task examining infants' ability to reason about a partly hidden object (Hespos & Baillargeon, 2001a). In this experiment, 5.5-, 6.5-, and 7.5-month-old infants saw two test events. At the start of each event, an experimenter's gloved hand grasped a knob at the top of a tall cylindrical object; next to the object was a tall (expected event) or a short (unexpected event) container. In both events, the hand lifted the object and lowered it into the container until only the knob remained visible above the rim of the container. The 5.5- and 6.5-month-old infants tended to look equally at the two test events. Only the 7.5-month-old infants looked reliably longer at the unexpected than at the expected event, suggesting that they realized that the cylindrical portion of the object could be fully hidden inside the tall but not the short container. This conclusion was supported by the results of a control condition carried out using an object with a shorter cylindrical portion that could be fully hidden inside either container; the infants in this condition looked about equally at the two test events.

Experiment 1 attempted to extend these results in two ways: it examined younger, 4-month-old infants in a test-only VOE task involving a fully rather than a partly hidden object. Because there is little debate about young infants' ability to represent *partly* hidden objects (e.g. Harris, 1987; Johnson, 1997; Kellman & Spelke, 1983; Needham, 1998; Needham & Ormsbee, in press; Spelke, 1991; Yonas & Granrud, 1984), it was essential for present purposes to use a task involving a *fully* hidden object.

2. Experiment 1

The point of departure for Experiment 1 was the finding that 4.5-month-old infants attend to width information in occlusion events: they are surprised when two objects become hidden behind an occluder too narrow to hide them both at once (e.g. Wilcox, 1999; Wilcox & Baillargeon, 1998). These results were obtained using VOE tasks with familiarization trials. Experiment 1 asked whether 4-month-old infants would also give evidence that they attend to width information in occlusion events, in a test-only VOE task.

The infants saw two test events (see Fig. 1). At the start of each event, an experimenter's gloved hand grasped a knob attached to a wide rectangular object, and

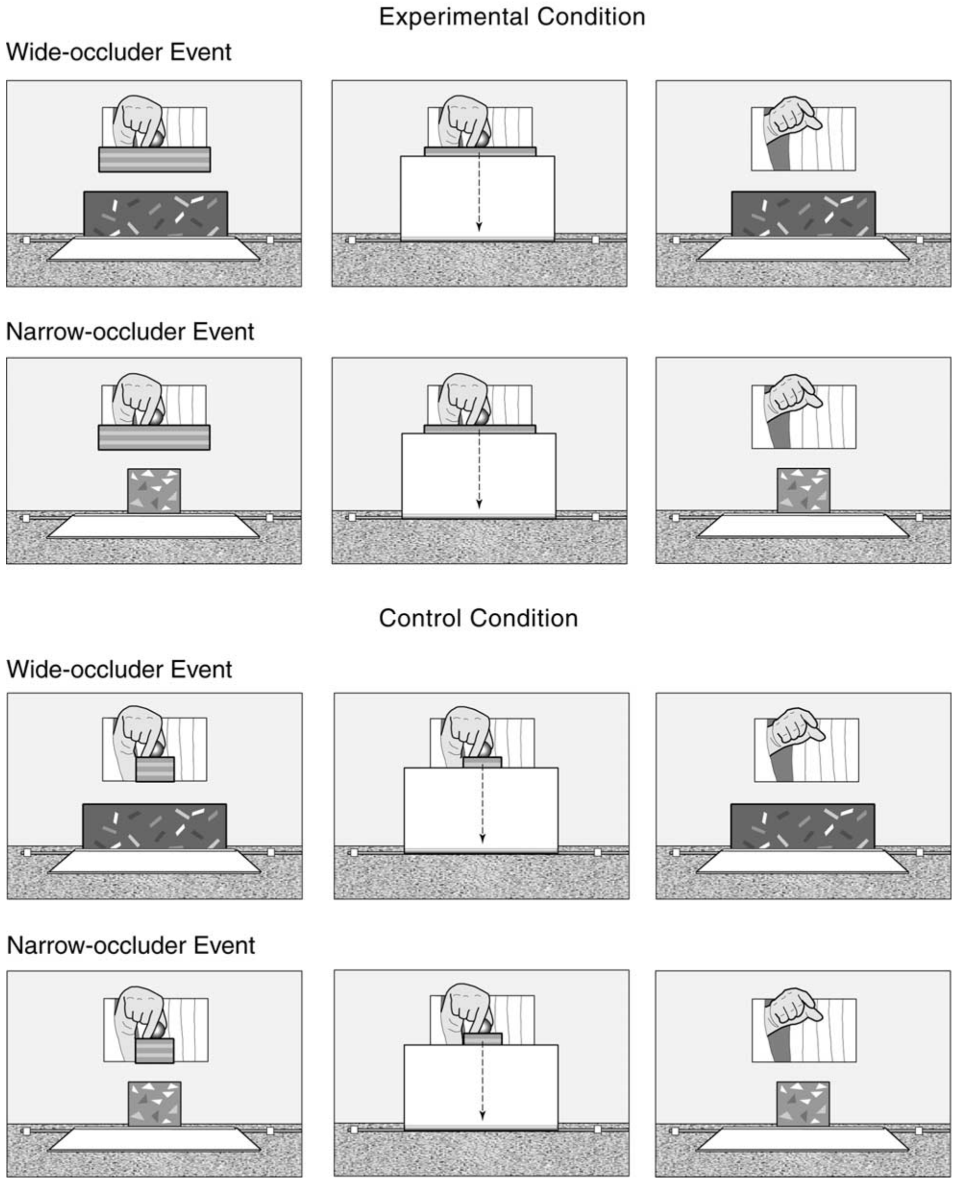

Fig. 1. Schematic drawing of the test events shown in the experimental and control conditions of Experiment 1.

held this object above and behind a wide (wide-occluder event) or a narrow (narrow-occluder event) wooden occluder. After a pause, a large screen was raised to hide the occluder; the hand and the top of the object remained visible above the screen. Next, the hand lowered the object straight down to the apparatus floor behind the occluder; the hand then released the object and returned to its original position above the screen.

Finally, the screen was lowered to reveal the occluder standing alone on the apparatus floor. Infants in a control condition saw the same test events except that the rectangular portion of the object was much narrower and could be fully hidden behind either occluder (see Fig. 1).

If the infants believed that the object continued to exist after it became hidden, and realized that the width of the object relative to that of the occluder determined whether the object could be fully or only partly hidden behind the occluder, then two predictions followed. First, the infants in the experimental condition should expect the wide object to be fully hidden behind the wide but not the narrow occluder, and they should be surprised when this last expectation was violated; they should therefore look reliably longer at the narrow- than at the wide-occluder event. Second, the infants in the control condition should expect the narrow object to be fully hidden behind either occluder, and they should therefore tend to look equally at the two events.

We reasoned that such results would not only confirm previous findings that young infants attend to width information in occlusion events (e.g. Wilcox, 1999; Wilcox & Baillargeon, 1998), but would also provide converging evidence, using a test-only VOE task, that young infants can represent and reason about hidden objects.

2.1. Method

2.1.1. Participants

Participants were 32 healthy term infants, 16 male and 16 female (range = 3 months, 17 days to 4 months, 6 days, $M = 3$ months, 24 days). An additional 14 infants were tested but eliminated, 7 because they looked for the maximum amount of time allowed (60 s) on both test trials, 5 because they were inattentive or distracted, 1 because the observers had difficulty determining the direction of the infant's gaze, and 1 because the difference in the infant's looking times in the two test trials was more than 2.5 standard deviations from the mean for the same condition. Half of the infants were randomly assigned to the experimental condition ($M = 3$ months, 22 days), and half to the control condition ($M = 3$ months, 26 days).

The infants' names in this and in the following experiment were obtained from birth announcements published 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 consisted of a wooden display box 106 cm high, 101 cm wide, and 42.5 cm deep that was mounted 76 cm above the room floor. The back wall of the apparatus was made of white foam core, the side walls were covered with gray marbled contact paper, and the floor was covered with gray granite-textured contact paper. The infant faced an opening 40 cm high and 95 cm wide in the front wall of the apparatus. Between trials, a curtain consisting of a wooden frame 61 cm high, 100 cm wide, and covered with white muslin was lowered in front of this opening. The primary experimenter introduced her right hand (in a long white glove) into the apparatus through a window

16.5 cm high and 27 cm wide centered in the back wall, 14 cm above the floor; the window was filled with a white muslin fringe.

The wide and narrow objects were both 5 cm high, 5 cm deep, made of wood, painted light blue, and decorated with royal blue horizontal stripes; each object had a round wooden knob, 3.5 cm in diameter and painted red, centered on its top surface. The wide object was 23 cm wide, and the narrow object 8 cm wide.

The wide and narrow occluders were both 10 cm high, 2 cm deep, and made of wood. The wide occluder was 28 cm wide, painted dark purple, and decorated with small colorful rectangles. The narrow occluder was 10 cm wide, painted dark green, and decorated with small colorful triangles. At the bottom of each occluder were two metal posts, each 0.5 cm in diameter and 2 cm long; these posts were inserted into two small holes, each 0.5 cm in diameter, in the apparatus floor, to keep the occluder in position.

A white cardboard screen, 16.5 cm high, 31.5 cm wide, and 0.25 cm thick, was mounted on a metal rod 0.75 cm in diameter and 94.5 cm long. The rod was attached to the apparatus floor with brackets, and protruded through an opening in the right wall. By turning the right end of the rod, the secondary experimenter could raise the screen 90°. The screen was positioned 25 cm from the front of the apparatus, centered between the side walls.

In each test event, the object was surreptitiously removed and replaced when the screen was raised. Each occluder stood centered behind the screen. Centered in the apparatus floor behind the occluder was a trapdoor that could be slid backward under the back wall. A platform under the apparatus, covered with the same gray granite-textured contact paper as the apparatus floor, could then be lifted (the tertiary experimenter turned a crank linked to the platform with string and pulleys) to fill the open trapdoor. After the primary experimenter deposited the wide or narrow object on the platform behind the occluder, the platform was lowered (whisking away the object) and the trapdoor closed. These actions were reversed to replace the object.

The infants were tested in a brightly lit room. One 150-W, one 60-W, and three 40-W lamps attached to the front and back wall of the apparatus provided additional light. Two frames, each 183 and 71 cm wide and covered with green cloth, stood at an angle on either side of the apparatus; these frames served to isolate the infants from the experimental room.

2.1.3. Events

Three experimenters worked in concert to produce the test events: the primary experimenter manipulated the wide or narrow object with her gloved right hand, and the trapdoor in the apparatus floor with her left hand; the secondary experimenter operated the screen; and the tertiary experimenter operated the platform under the apparatus floor. To help the experimenters adhere to the events' scripts, a metronome beat softly once per second. In the following text, the numbers in parentheses indicate the time taken to perform the actions described.

Experimental condition. At the start of each test event, the screen lay flat on the apparatus floor; the gloved hand grasped the knob at the top of the wide object, which she held centered 3.5 cm above and 2.5 cm behind the wide (wide-occluder event) or narrow (narrow-occluder event) occluder. The experimenter maintained her position until the computer signaled that the infant had looked at this static display for 2 cumulative seconds. This pretrial gave the infants the opportunity to inspect the object and occluder and to compare their widths.

Following the pretrial, the test event properly began. To start, the screen was raised upward 90° to hide the occluder (1 s); the hand, knob, and top 2 cm of the object remained visible above the screen. Next, the hand lowered the object straight down behind the occluder (2 s); during these same 2 s, out of view, the trapdoor in the apparatus floor was slid open, and the platform under the floor was lifted to fill the open trapdoor. After depositing the object on the platform, the hand slowly rose until it was 3.5 cm above the screen (3 s); during these same 3 s, out of view, the platform was lowered (with the object) and the trapdoor closed. The screen was then lowered (2 s) to reveal the occluder standing alone on the apparatus floor. After a 1-s pause, the sequence was repeated in reverse. The screen was raised (1 s), and the hand slowly returned behind the screen (3 s); during these same 3 s, the trapdoor was slid open and the platform, carrying the object, was lifted to fill the open trapdoor. The hand then grasped the object and lifted it above the screen (2 s); during these same 2 s, the platform was lowered and the trapdoor closed. Finally, the screen was lowered to reveal the occluder (2 s). There was a 1-s pause, and then the entire sequence was repeated. Each event cycle thus lasted about 18 s; cycles were repeated until the computer signaled that the trial had ended (see below).

Control condition. The wide- and narrow-occluder test events shown in the control condition were identical to those in the experimental condition except that the wide object was replaced with the narrow object.

2.1.4. Procedure

Each infant sat on a parent's lap in front of the apparatus, about 21 cm from the closed curtain. Parents were instructed to remain quiet and neutral, and to keep their eyes closed during the trials. To minimize the possibility of transient novelty or familiarity effects, infants were not shown any of the test objects (e.g. the wide or narrow object, the wide or narrow occluder, the screen, or the gloved hand) before the experiment. When the curtain was raised at the beginning of the first test trial, the infant saw the interior of the apparatus and the objects in it for the first time.

The infants received only two test trials (again to minimize the possibility of novelty or familiarity effects emerging across trials). In each condition, half of the infants saw the narrow-occluder event on the first trial and the wide-occluder event on the second trial, and half of the infants saw the two events in the reverse order.

Two observers watched each infant through peepholes in the cloth-covered frames on either side of the apparatus. The observers could not see the test events from their viewpoints, and they did not know the order in which they were presented or the condition to which the infant was assigned. Each observer depressed a button linked to a computer when the infant looked at the event. The looking times recorded by the primary (typically more experienced) observer were used to determine the endings of the trials. Each trial ended when the infant either (1) looked away from the event for 1 consecutive second after having looked at it for at least 12 cumulative seconds (beginning after the pretrial, when the screen was raised) or (2) looked at the event for 60 cumulative seconds. The 12-s minimum value was chosen to ensure that the infants had the opportunity to view and process each event.

Interobserver agreement was calculated for 31 of the 32 infants (only one observer was present for one infant). Each trial was divided into 100-ms intervals, and the computer determined in each interval whether the observers agreed that the infant was or was not looking at the event. Percent agreement was calculated by dividing the number of intervals in which the observers agreed by the total number of intervals in the trial. Agreement averaged 95% per trial per infant.

Preliminary analyses of the data revealed no significant effect involving sex, all $Fs(1,28) < 1.04$, $P > 0.10$; the data were therefore collapsed across this factor in subsequent analyses.

2.2. Results

Fig. 2 presents the infants' mean looking times at the test events. It can be seen that the infants in the experimental condition looked longer at the narrow- than at the wide-occluder event, but that those in the control condition looked about equally at the two events.

The infants' looking times were compared by means of a $2 \times 2 \times 2$ analysis of variance (ANOVA) with condition (experimental or control) and order (narrow- or wide-occluder event first) as a between-subjects factor and event (narrow- or wide-occluder) as a within-subject factor. The analysis yielded a significant main effect of event, $F(1,28) = 6.61$, $P < 0.025$, and a significant condition $\times$ event interaction, $F(1,28) = 5.58$, $P < 0.05$. Planned comparisons indicated that the infants in the experimental condition looked reliably longer at the narrow- ($M = 41.7$, $\mathrm{SD} = 16.8$) than at the wide-occluder event ($M = 26.0$, $\mathrm{SD} = 14.7$), $F(1,28) = 12.17$, $P < 0.0025$, whereas those in the control condition tended to look equally at the two events, $F(1,28) = 0.02$ (narrow-occluder event $M = 28.1$, $\mathrm{SD} = 16.8$; wide-occluder event $M = 27.4$, $\mathrm{SD} = 13.8$). Non-parametric Wilcoxon signed-ranks tests confirmed the results of the experimental ($T = 24$, $P < 0.025$) and control ($T = 66$, $P > 0.10$) conditions.

2.3. Discussion

The infants in the experimental condition looked reliably longer at the narrow- than at the wide-occluder event, whereas those in the control condition looked equally at the two events. These results suggest that the infants (1) believed that the wide or narrow object continued to exist after it became hidden; (2) recognized that the narrow object could be fully hidden behind either occluder, and that the wide object could be fully hidden behind the wide but not the narrow occluder; and (3) were surprised when this last expectation was violated.

These results confirm prior findings (e.g. Wilcox, 1999; Wilcox & Baillargeon, 1998) that young infants attend to width information when predicting the outcome of occlusion events. In addition, the present results provide evidence that young infants can detect a violation involving a hidden object even when given a VOE task with *no* habituation or familiarization trials.

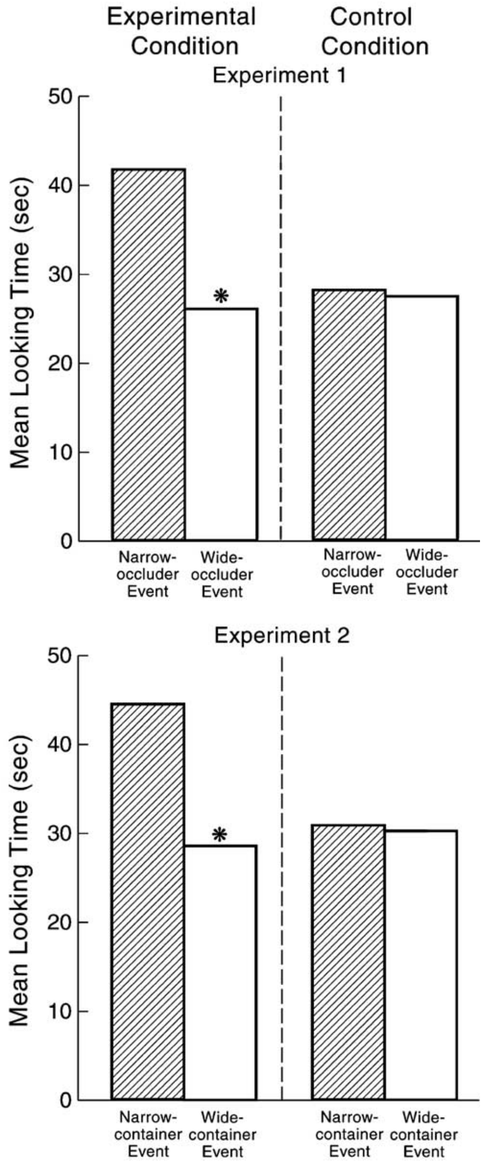

Fig. 2. Mean looking times of the infants in the experimental and control conditions of Experiments 1 and 2 at the test events.

3. Experiment 2

Experiment 2 sought to confirm the findings of Experiment 1: it used a similar procedure except that the occluders were replaced with containers, so that the infants saw containment rather than occlusion events (see Fig. 3). Prior research (e.g. Aguiar &

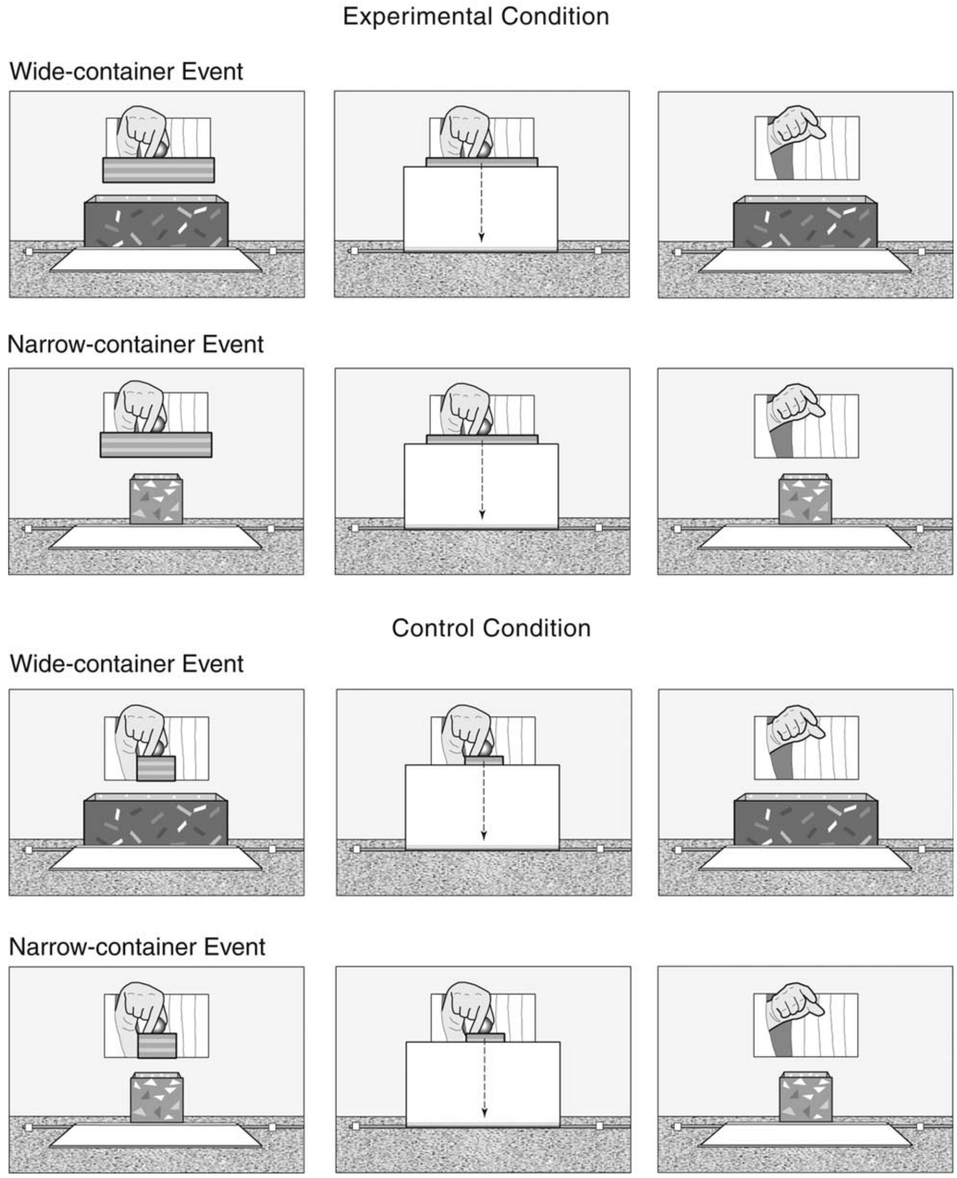

Fig. 3. Schematic drawing of the test events shown in the experimental and control conditions of Experiment 2.

Baillargeon, 1998, 2003; Sitskoorn & Smitsman, 1995) indicates that infants aged 6 months and older attend to width information in containment events: infants are surprised when a wide object is lowered into a narrow container. These results were obtained using VOE tasks with habituation or familiarization trials. Experiment 2 thus examined whether similar results would be obtained with 4-month-old infants, in a test-only VOE task.

A secondary goal of Experiment 2 was to test a prediction concerning young infants' ability to attend to width information in containment events (Baillargeon, 2002; Hespos & Baillargeon, 2001a). This prediction was derived from research on infants' reasoning about height information in occlusion and containment events. As we saw in the Introduction, infants begin to attend to height information in containment events at about 7.5 months of age (e.g. Hespos & Baillargeon, 2001a, 2004). However, infants begin to attend to height information in occlusion events several months earlier, at about 3.5 months of age (e.g. Aguiar & Baillargeon, 2002; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987; Hespos & Baillargeon, 2001a). Because even 2.5-month-old infants can predict the outcomes of various containment events (e.g. Hespos & Baillargeon, 2001b), this décalage cannot reflect an inability to reason about containers as opposed to occluders. How then, should it be explained?

To address this question, Hespos and Baillargeon appealed to their general account of how infants acquire physical knowledge (e.g. Baillargeon, 2002; Hespos & Baillargeon, 2001a,b). According to this account, infants form distinct event categories, such as occlusion, containment, and support events (e.g. Aguiar & Baillargeon, 2003; Casasola, Cohen, & Chiarello, 2003; Hespos & Baillargeon, 2001a, 2004; Luo & Baillargeon, 2004; McDonough, Choi, & Mandler, 2003; Wang et al., in press). For each event category, infants identify a series of variables that enables them to predict outcomes within the category more and more accurately over time (e.g. Baillargeon, 1991; Baillargeon, Needham, & DeVos, 1992; Kotovsky & Baillargeon, 1998; Wang, Kaufman, & Baillargeon, 2003). In this account, variables are akin to condition–outcome rules: for a set of contrastive outcomes, a variable specifies what condition produces each outcome. For example, the containment variable width specifies that an object *can* be inserted into a container if it is *narrower* than the opening of the container, but *cannot* be inserted if it is *wider* than the opening. The identification of a new variable in an event category involves several steps, including (1) noticing contrastive outcomes for the variable and (2) identifying the conditions that map onto these outcomes. According to Hespos and Baillargeon, the décalage in infants' identification of the variable height in occlusion and containment events has to do with this second step.

To identify the variable height in occlusion and containment events, infants must compare the heights of objects and occluders or containers. Prior research (e.g. Baillargeon, 1991, 1994a, 1995) indicates that when infants begin to reason about a continuous variable in an event category, they can reason about the variable qualitatively but not quantitatively: they are not able at first to encode and remember absolute amounts. In order to encode the heights of objects and occluders or containers qualitatively, infants must compare them as they stand *side by side*. According to Hespos and Baillargeon (e.g. Baillargeon, 2002; Hespos & Baillargeon, 2001a,b), infants may have more opportunities to perform such comparisons with occlusion than with containment events. In the case of occlusion events, infants will often see objects move behind the side edges of occluders, making it easy to compare their heights as they stand next to each other (e.g. when a parent steps behind a chair, or a pot is pushed in front of a bowl). In the case of containment events, however, there may be few instances in which objects are placed first next to and then inside containers; caretakers will more often lower objects directly into containers, giving infants no opportunity to compare their heights.

The preceding reasoning suggests that in containment events, infants should identify the variable *width* before the variable height, because each time an object is lowered inside a container (e.g. when a spoon is lowered into a jar, or a toy into a bucket), their widths can be compared qualitatively as one is held above the other. Furthermore, there should be little or no décalage in the identification of the variable width in occlusion and containment events: infants should be able to gather the needed qualitative width information as objects are lowered behind occluders or inside containers.

The results of Experiment 1 suggested that 4-month-old infants have already identified the variable width in occlusion events. According to the preceding speculations, although there is a marked décalage in infants' reasoning about the variable *height* in occlusion and containment events, there is no reason to expect a parallel décalage in infants' reasoning about the variable *width* in these events. The results of Experiment 2 were thus expected to mirror those of Experiment 1.

3.1. Method

3.1.1. Participants

Participants were 32 healthy term infants, 15 male and 17 female (range = 3 months, 18 days to 4 months, 8 days, $M = 3$ months, 27 days). An additional 19 infants were tested but eliminated, 8 because they looked for the maximum amount of time allowed (60 s) during both test trials, 6 because the observers had difficulty determining the direction of the infants' gaze, and 5 because they were fussy, inattentive, or distracted. Half of the infants were randomly assigned to the experimental condition ($M = 3$ months, 26 days), and half to the control condition ($M = 3$ months, 29 days).

3.1.2. Apparatus

The apparatus used in Experiment 2 was identical to that in Experiment 1 with three exceptions. First, a three-sided form was added at the back of each occluder so that together they formed a container. To ensure that the infants noticed that they were facing a container, the back wall of each container was 1.5 cm taller than the front wall, and the side walls angled slightly to join them; each side wall was 0.7 cm thick, and both containers were 13 cm deep. The exterior of each container was painted the same dark color as the front wall; the interior was painted apricot and decorated with white dots, so that it contrasted with the exterior and was easy to detect. Second, the back wall of each container rested in a Plexiglas holder (out of view) attached to the trapdoor in the apparatus floor. When the trapdoor was slid backwards, the three-sided form moved with it, making it possible for the primary experimenter to deposit the wide or narrow object on the lifted platform, which could then be lowered to whisk away the object. When the trapdoor was slid forward, the three-sided form abutted the front wall once more to form the container. Finally, the back wall of the apparatus was moved back 13 cm to accommodate the depth of the containers.

3.1.3. Events and procedure

The events and procedure used in Experiment 2 were identical to those in Experiment 1 except that the wide and narrow containers replaced the wide and narrow occluders. Interobserver agreement was calculated for 28 of the 32 infants and averaged 94% per trial per infant.

Preliminary analyses of the data revealed no significant interaction involving sex, all $F\text{s}(1, 28) < 0.65$; the data were therefore collapsed across this factor in subsequent analyses.

3.2. Results

The infants' mean looking times at the test events are shown in Fig. 2. It can be seen that the infants in the experimental condition looked longer at the narrow- than the wide-container event, but that those in the control condition tended to look equally at the two events.

The infants' looking times were analyzed by means of a $2 \times 2 \times 2$ ANOVA with condition (experimental or control) and order (narrow- or wide-container event first) as between-subjects factors and event (narrow- or wide-container) as a within-subject factor. The analysis yielded a significant main effect of event, $F(1, 28) = 6.69$, $P < 0.025$, and a significant condition × event interaction, $F(1, 28) = 5.86$, $P < 0.025$. Planned comparisons indicated that the infants in the experimental condition looked reliably longer at the narrow- ($M = 44.4$, SD = 15.8) than at the wide-container event ($M = 28.6$, SD = 15.2), $F(1, 28) = 12.55$, $P < 0.0025$, whereas those in the control condition looked about equally at the two events, $F(1, 28) = 0.01$ (narrow-container event $M = 30.8$, SD = 18.2; wide-container event $M = 30.2$, SD = 19.2). Non-parametric Wilcoxon signed-ranks tests confirmed the results of the experimental ($T = 20.5$, $P < 0.025$) and control ($T = 64$, $P > 0.10$) conditions.

The ANOVA also yielded a significant order × event interaction, $F(1, 28) = 4.48$, $P < 0.05$. Follow-up comparisons revealed that the infants who saw the narrow-container event first looked reliably longer at this event ($M = 41.1$, SD = 17.3) than at the wide-container event ($M = 26.2$, SD = 14.8), $F(1, 28) = 11.06$, $P < 0.0025$, whereas those who saw the wide-container event first tended to look equally at the two events, $F(1, 28) = 0.11$ (narrow-container $M = 34.1$, SD = 18.8; wide-container $M = 32.6$, SD = 19.0). Such order effects are relatively common in infancy research (e.g. Aguiar & Baillargeon, 1998, 2002, 2003; Baillargeon, 1986, 1987; Csibra, Gergely, Biro, Koos, & Brockbank, 1999; Gergely, Nadasdy, Csibra, & Biro, 1995; Kotovsky & Baillargeon, 1998). Because this order effect did not interact with condition ($F(1, 28) = 0.32$), it does not bear on the present hypotheses and will not be discussed further.

3.3. Discussion

The infants in the experimental condition looked reliably longer at the narrow- than at the wide-container event, whereas those in the control condition looked about equally at the two events. These results suggest that the infants (1) believed that the wide or narrow object continued to exist after it became hidden; (2) recognized that the narrow object could be hidden inside either container, and that the wide object could be hidden inside the wide but not the narrow container; and (3) were surprised when this last expectation was violated.

The results of Experiment 2 support three conclusions. First, they extend prior results that infants aged 6 months and older attend to width information in containment events (e.g. Aguiar & Baillargeon, 1998, 2003; Sitskoorn & Smitsman, 1995) to younger, 4-month-old infants.[4] Second, they confirm the prediction (Baillargeon, 2002; Hespos & Baillargeon, 2001a) that there should be little or no décalage in infants' reasoning about the variable width in occlusion and containment events. In the present research, 4-month-old infants were surprised when a wide object became fully hidden either behind a narrow occluder or inside a narrow container.[5] These results differ markedly from those obtained in investigations of infants' reasoning about the variable height: recall that infants begin to attend to height information at about 3.5 months in occlusion events, but only at about 7.5 months in containment events (e.g. Aguiar & Baillargeon, 2002; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987; Hespos & Baillargeon, 2001a, 2004). As such, the present results generally support the proposal that (1) infants show little or no décalage in their acquisition of the same continuous variable in two different event categories when they have about equal opportunity to gather qualitative information about the variable in the two categories (e.g. width in occlusion and containment events); and in contrast (2) infants show a décalage in their acquisition of the same continuous variable in

[4] Sitskoorn and Smitsman (1995) found that 6- but not 4-month-old infants could reason about width information in containment events. We suspect that the discrepancy between their results and those of Experiment 2 is due to the fact that their task was more difficult. In their unexpected event, a block 16.5 cm wide was lowered inside a container 20 cm wide with an opening 15 cm wide (the container's side rims were partly collapsible). The violation involved was thus quite subtle: the block was narrower than the container, but 1.5 cm wider than its opening. In Experiment 2, in contrast, the wide object was 23 cm wide and the narrow container 10 cm wide. The object was thus more than twice as wide as the container, so that even a cursory comparison of the object and container was sufficient to establish that one could not be lowered inside the other. There already is evidence that, after identifying a continuous variable as being relevant to an event category, infants detect more and more subtle violations of the variable over time (e.g. Baillargeon, 1991).

[5] There may be situations in which infants respond differently to width violations in occlusion and containment events. In particular, infants may be able, under some conditions, to generate explanations for occlusion width violations. To see why, consider once again the narrow-occluder event in the experimental condition of Experiment 1. Although the wide object was lowered through a trapdoor in the apparatus floor, a simpler way to produce the event would have been for the hand to *rotate* the object 90° when out of view behind the screen (recall that the object was 23 cm wide and 5 cm deep, and the narrow occluder 10 cm wide). A rotation could not have been used to produce the narrow-container event in the experimental condition of Experiment 2, because in either orientation the object was too wide to fit inside the container (recall that the narrow container was 10 cm wide and 13 cm deep). Could infants at some age generate a rotation explanation for the narrow-occluder event? Previous research suggests that infants can sometimes generate explanations for apparent violations of their physical knowledge (e.g. Aguiar & Baillargeon, 2002; Baillargeon, 1994b; Spelke et al., 1995a; Wang et al., 2003; Xu & Carey, 1996). If infants at some age did generate a rotation explanation for the narrow-occluder event, then they should respond with increased attention to the narrow-container but *not* the narrow-occluder event. However, infants should respond with increased attention to *both* events when given information contradicting a rotation explanation (e.g. if the object used was as deep as it was wide, so that it could not be fully hidden when rotated behind the narrow occluder). Such evidence would add to our understanding of the conditions under which infants succeed in generating explanations that reconcile what they see with what they know.

two different categories when they have greater opportunity to gather qualitative information about the variable in one category than in the other (e.g. height in occlusion and containment events).

Finally, and most importantly for present purposes, the results of Experiment 2 confirm those of Experiment 1, and provide additional evidence that young infants can detect a violation involving a hidden object even when given a VOE task with *no* habituation or familiarization trials.

4. Novelty or familiarity effects across test trials?

Although the infants in Experiments 1 and 2 received no habituation or familiarization trials, they did receive two test trials. It might be suggested that a transient novelty or familiarity preference for the experimental narrow-occluder or narrow-container event could perhaps have emerged in the course of these two trials.

To examine this possibility, we analyzed the looking times of the infants in Experiments 1 and 2 during their *first* test trial only. The data were compared by means of a $2 \times 2 \times 2$ ANOVA with experiment (1 or 2), condition (experimental or control), and event (narrow-occluder/container or wide-occluder/container) as between-subjects factors. The analysis revealed a significant main effect of condition, $F(1,56) = 6.18$, $P < 0.025$, and a significant condition × event interaction, $F(1,56) = 6.27$, $P < 0.025$; no other effect was significant. Planned comparisons indicated that the experimental infants who saw the narrow-occluder/container event in their first trial ($M = 47.7$, SD = 13.6) looked reliably longer than did those who saw the wide-occluder/container event ($M = 31.5$, SD = 18.8), $F(1,56) = 8.07$, $P < 0.01$, whereas the control infants who saw the narrow-occluder/container event ($M = 27.5$, SD = 15.1) and those who saw the wide-occluder/container event ($M = 31.5$, SD = 16.1) tended to look about equally, $F(1,56) = 0.49$.

Additional planned contrasts indicated that the experimental infants who saw the narrow-occluder/container event in their first trial looked reliably longer than did the other three groups of infants, $F(1,56) = 14.12$, $P < 0.0005$, who did not differ reliably among themselves, $F(1,56) = 0.65$.

The infants thus gave evidence in their *first* test trial that they detected the violation in the experimental narrow-occluder or narrow-container event. Such evidence contradicts the possibility that the results of Experiments 1 and 2 reflect only a transient novelty or familiarity preference that emerged in the course of the two test trials.

5. Novelty or familiarity effects within each test trial?

It might be suggested that, although the infants in Experiments 1 and 2 received no habituation or familiarization trials and gave evidence in their first test trial that they detected the violation in the experimental narrow-occluder or narrow-container event, their responses could still reflect a transient novelty or familiarity preference that developed *within* each test trial.

Cohen and Marks (2002) proposed an analysis of findings by Wynn (1992) along these lines. In Wynn's experiment, 5-month-old infants were assigned to an addition or a subtraction condition. In the addition condition, a toy was placed on an apparatus floor, and then a screen was raised to hide the toy. Next, a second identical toy was deposited behind the screen. Finally, the screen was lowered to reveal either one toy (one-toy display) or two toys (two-toy display). In the subtraction condition, two toys were placed on the apparatus floor, and then the screen was raised to hide them. Next, one of the toys was removed, and the screen was again lowered to reveal either one or two toys. The infants in the addition condition looked reliably longer at the one- than at the two-toy display, whereas those in the subtraction condition showed the reverse looking pattern. Cohen and Marks suggested that the infants showed a familiarity preference: when the toy (addition condition) or toys (subtraction condition) were placed on the apparatus floor at the start of each trial, the infants did not have time to fully process this initial display. As a result, when the screen was lowered, the infants tended to look longer at the final display that matched the initial display, so they could continue processing it.

Whatever the merits of this interpretation (see Wynn, 2002, for a rebuttal), one might ask whether the present results could be subjected to a similar analysis. At the start of each test event, the infants saw two stimuli, an object held above an occluder or a container. More specifically, the infants saw: (1) a wide object above a narrow occluder or container; (2) a wide object above a wide occluder or container; (3) a narrow object above a narrow occluder or container; or (4) a narrow object above a wide occluder or container. After the screen was lowered, the infants saw a single stimulus, the occluder or container shown at the start of the event. The situation here was thus different from that in Wynn (1992): the display shown after the screen was lowered *always* involved one fewer stimulus than the display shown before the screen was raised. Under these conditions, there is no obvious reason why the infants who saw (1) above should have been more likely to display a familiarity preference than those who saw (2), (3), or (4). In each case, the only stimulus visible after the screen was lowered was the occluder or container shown before the screen was lowered.

6. General discussion

Findings from various VOE tasks over the past 20 years suggest that young infants represent the continued existence of objects that become hidden (e.g. Aguiar & Baillargeon, 2002; Hespos & Baillargeon, 2001a,b; Luo & Baillargeon, in press; Luo et al., 2003; Wang et al., in press; Wilcox & Schweinle, 2002, 2003; see Baillargeon, 2000, for a partial listing of earlier reports). In this article, we considered several alternative accounts of these VOE findings (e.g. Bogartz et al., 2000, 1997; Cashon & Cohen, 2000; Roder et al., 2000; Schilling, 2000; Thelen & Smith, 1994). Despite their differences, all these accounts attribute infants' apparent success in previous VOE tasks to transient novelty or familiarity preferences that emerge in the course of the habituation or familiarization trials. As such, all these accounts make the same prediction: young infants should fail to give evidence that they can represent hidden objects when given *no* habituation or familiarization trials. Without such trials, infants should have no opportunity to develop a novelty or a familiarity preference that might contribute to their responses to the expected and unexpected events shown in the test trials, and they should therefore look about equally at the events. The present research was designed to test this prediction.

Two experiments examined 4-month-old infants' ability to reason about width information in occlusion (Experiment 1) and in containment (Experiment 2) events. These experiments built on previous research which suggested that (1) 4.5-month-old infants can reason about the variable width in occlusion events (e.g. Wilcox, 1999; Wilcox & Baillargeon, 1998); and (2) unlike the variable height, the variable width should be identified at about the same age in occlusion and in containment events (e.g. Baillargeon, 2002; Hespos & Baillargeon, 2001a,b). To guard against the possibility of novelty or familiarity preferences emerging before the test trials, the infants received *no* habituation or familiarization trials, and they did not see the test objects or the interior of the apparatus prior to the test session; the curtain at the front of the apparatus was raised for the first time at the start of the first test trial.

The infants in the present research saw two test events in two successive trials. In Experiment 1, the infants in the experimental condition saw a wide (experimental condition) or a narrow (control condition) object become fully hidden behind a wide or a narrow occluder. In Experiment 2, the infants saw similar events except that the wide and narrow occluders were replaced with wide and narrow containers. The infants looked reliably longer when the wide object became fully hidden behind the narrow as opposed to the wide occluder, and inside the narrow as opposed to the wide container. No reliable difference was found in either experiment when the narrow object was used. The infants thus gave evidence that they could represent and reason about a hidden object even when tested without habituation or familiarization trials.

In addition to examining the infants' responses in the two test trials they received, we also examined their responses in the *first* test trial only. The results were similar to those reported above: the infants who saw the wide object become fully hidden behind the narrow occluder or inside the narrow container looked reliably longer than those who saw the wide object become fully hidden behind the wide occluder or inside the wide container. No reliable difference was found in the looking times of the infants who saw events involving the narrow object. The infants thus gave evidence that they could represent and reason about a hidden object even when given a single test trial.

The present results thus provide strong support for the conclusion, suggested by previous VOE reports, that young infants represent the continued existence of objects that become hidden.

6.1. Possible role of habituation or familiarization trials in VOE tasks

In light of the present findings, should we expect young infants to succeed in all the VOE tasks with hidden objects that have yielded positive results to date, if tested again *without* habituation or familiarization trials? We think not. In VOE tasks involving novel self-moving objects, unfamiliar motions, complex event sequences, and so on, habituation or familiarization trials very likely play a crucial role: that of acquainting infants with these various objects, motions, or events, so that they can better focus in the test trials on the key manipulations introduced by the researchers. Without these *orientation* trials, infants might well fail, because the test events introduce too much information for them to handle at once, thus overwhelming their limited processing resources.

An experiment by Rivera, Wakeley, and Langer (1999) could be taken to provide support for the preceding speculations. In their experiment, 5.5-month-old infants saw test events modeled after those of Baillargeon (1987). In her experiment, Baillargeon habituated 4.5-month-old infants to a screen that rotated back and forth through a 180° arc. In the test events, a box was placed behind the screen, and the screen either rotated 112° until it reached the hidden box (expected event), or rotated 180° as though the box was no longer present (unexpected event). Infants in a control condition saw similar habituation and test events except that no box was present. The infants in the experimental condition looked reliably longer at the unexpected than at the expected event, whereas those in the control condition tended to look equally at the two events. Rivera et al. showed their infants similar test events, but gave them no habituation trials. The infants in the experimental condition received three familiarization trials in which they saw the box (first trial), and a single 112° or 180° screen rotation with no box present (second and third trials); the infants in the control condition received no familiarization trials. The infants in both conditions showed a weak but reliable preference for the 180° over the 112° screen rotation. The authors concluded that the infants in Baillargeon's experimental condition displayed a "simple perceptual preference for more motion" (Rivera et al., 1999. p. 427). This conclusion is unlikely, however, because the infants in Baillargeon's control condition, who saw the same screen rotations, failed to display the same perceptual preference for "more motion" (Baillargeon (1987) also obtained similar results with 3.5-month-old infants, as described below; see also Baillargeon et al. (1985), Durand and Lécuyer (in press), and Slater, Hayes, Quinn, Haldorsson, and Brown (2004), for additional replications of the experimental and control results just described).

A more likely interpretation of the findings of Rivera et al. (1999), we would argue, and one consistent with the speculations offered above, is that young infants *cannot* predict what should happen when a box is placed behind a self-moving, rotating screen, *unless* they are first made familiar with the screen's motion.[6] How often in everyday life are

[6] This conclusion should be accepted with caution, because there were many differences between the experiments of Baillargeon (1987) and Rivera et al. (1999) that could have resulted in these authors' failure to replicate her results. We make only two points here. First, in Baillargeon's experiment, 23 infants completed three or four test pairs, and 4 did not because of fussiness; in the experiment of Rivera et al., 51 infants completed three or four test pairs, and 29 did not because of fussiness. This difference is especially striking when one considers that Baillargeon's infants received 6 to 9 habituation trials prior to test, whereas Rivera et al.'s infants did not, and so were presumably less fatigued during the test trials. It is unclear why Rivera et al.'s infants tended to be fussy, though some guesses are possible: the infants were tested in a dark rather than a brightly lit room; they were positioned 100 cm rather than 65 cm from the screen; and the average intertrial interval was 10 s rather than 2 to 3 s. These various factors may all have tended to make the task less engaging for the infants.A second difference between the experiments of Baillargeon (1987) and Rivera et al. (1999) has to do with the minimum look set for each test trial. As is typically done in VOE tasks, Baillargeon set a minimum-look criterion for each test trial (5 cumulative seconds, or the duration of one 180° rotation) that gave the infants the opportunity to distinguish between the two screen rotations. Rivera et al., however, did not use a minimum-look criterion. A test trial ended when the infant looked away for 2 consecutive seconds—even if the infant had looked at the rotating screen for only 1 or 2 cumulative seconds (as in Baillargeon's experiment, the screen took 5 s to complete a 180° rotation). Such a practice could well have undermined the infants' ability to respond appropriately to the test events: infants obviously cannot distinguish between events they have not seen. Unfortunately, several researchers in recent years have failed to appreciate this methodological safeguard, a point we return to later on (e.g. Bogartz et al., 1997; Cashon & Cohen, 2000).

infants exposed to objects that rotate spontaneously about their lower edge through a 180° arc? It does not seem surprising that infants would need to be familiarized with a self-moving, rotating screen before they could reason about the consequences of introducing obstacles in its path.

Support for the preceding analysis comes from findings, also reported in Baillargeon (1987), that 3.5-month-old infants showed the same looking patterns as 4.5-month-old infants (i.e. reliably longer looking times at the 180° than at the 112° rotation with the box present but not absent) *only* if they were fast habituators; 3.5-month-old infants who were slow habituators tended to look equally at the two rotations, with the box present or absent.[7] These data suggest that grasping how the rotating screen moves through space is not an easy task for 3.5-month-old infants; and that only those who are able to do so can then go on to predict what should happen when a box is placed in its path.

In this section, we have suggested that in order to succeed in some VOE tasks infants may require habituation or familiarization trials that orient them to the tasks. We should also point out that providing infants with habituation or familiarization trials they do *not* require can sometimes have a detrimental effect. For example, Baillargeon, Kotovsky, and Needham (1995) found that 6.5-month-old infants succeeded at the rotating screen task if they were given a single familiarization trial with the 180° screen rotation prior to the test trials, but not if they were habituated to this rotation. Similarly, Hespos and Baillargeon (2001a) reported that 7.5-month-old infants were surprised when a tall object became almost fully hidden inside a short container if they received no familiarization trials prior to the test trials, but not if they were first given four familiarization trials. Presumably, infants who are given superfluous orientation trials become bored with the task and process the test events only minimally, resulting in an unsuccessful performance. The optimal number of orientation trials required in a VOE task thus appears to depend on both the nature of the task and the age of the infants tested.

6.2. Guarding against familiarity or novelty effects

If infants succeed in a VOE task involving hidden objects only when first given habituation or familiarization trials, how can we be certain that these trials did not induce a transient novelty or familiarity preference for the unexpected event shown in the test trials? The only recourse, as always, is to conduct experiments to evaluate specific hypotheses about such preferences. To illustrate, we consider again the three alternative transient-preference accounts described in the Introduction.

Car experiment. According to Thelen and Smith (1994), the infants in the car experiment (Baillargeon, 1986; Baillargeon and DeVos, 1991) looked reliably longer at the unexpected event because the box stood close to the screen and thus activated, prematurely, the second *screen* location in the habituation trajectory; the event thus no longer followed the course set by this trajectory. This account predicts that infants would look equally at the unexpected and expected events if the box was placed *in front* of, rather than behind, the car's path in the expected event. The box would then

[7] Infants were classified as fast habituators if they took 6 or 7 trials to reach the habituation criterion, and as slow habituators if they either took 8 or 9 trials to reach the criterion or failed to reach it altogether.

stand very close to the screen and as such would again activate the second *screen* location in the habituation trajectory. Infants would thus witness marked deviations from the trajectory in both the expected and the unexpected events, leading to about equal looking times at the two events. However, this was not the case: infants aged 4 to 8 months looked reliably longer at the unexpected than at the expected event whether the box was placed behind or in front of the car's path in the expected event (Baillargeon, 1986; Baillargeon & DeVos, 1991).

Rabbit experiment. According to Bogartz et al. (1997), the infants in the rabbit experiment (Baillargeon & Graber, 1987) looked reliably longer at the unexpected event because they focused on the tall rabbit's face, attended to the portion of the screen at the same height as the face, and noticed that the screen now sported a window. This account cannot explain the control results reported by Baillargeon and Graber (see also Baillargeon & DeVos, 1991). The infants in this control condition received two pretest trials at the start of the experiment in which they saw two tall or two short rabbits standing motionless on either side of the familiarization screen. The infants looked about equally at the unexpected and expected events, suggesting that they were able to take advantage of the two-rabbit "hint" they were given to make sense of the unexpected event (see also Aguiar & Baillargeon, 2002). Had the infants in the experimental and control conditions been limited to processing the portion of the screen at the same height as each rabbit's face, there should have been no difference between the responses obtained in the two conditions: the infants in both conditions should have simply detected the presence of the window in the unexpected event.

Several recent results have provided converging evidence that infants aged 3.5 months and older attend to height information in occlusion events (Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987). First, 4.5-month-old infants are surprised when an experimenter lowers a tall object behind a short occluder until it becomes almost fully hidden (Hespos & Baillargeon, 2001a). Second, 5-month-old infants are surprised when a tall object moves back and forth behind a tall screen with a high window, and the object extends only to the middle of the window (because the object is as tall as the screen, it should extend to the top of the window; Luo, Baillargeon, & Lécuyer, 2004). Finally, 6-month-old infants tested with an action rather than a VOE task were found to search for a tall object behind a tall as opposed to a short occluder (Hespos & Baillargeon, 2004).

In contrast to the above results, Bogartz et al. (1997) reported evidence that 5.5-month-old infants are not able to reason about the height of a hidden object. The infants were habituated to one of three events: a tall rabbit moving back and forth behind a windowless screen (no-window event); a tall rabbit moving back and forth behind a screen with a high window, and *appearing* in the window (rabbit-appears event); and a tall rabbit moving back and forth behind a screen with a high window, and *failing to appear* in the window (rabbit-does-not-appear event). Following habituation, the infants received three test trials in which they saw the same three events, in random order. Analyses of the habituation and test data revealed no reliable preference for the rabbit-does-not-appear event over the other two events. The main difficulty in interpreting these negative results is that the events and procedure used differed in so many respects from those of Baillargeon and Graber (1987) that firm conclusions are not possible. Even if we focus on the condition that most closely approximated the experiment of Baillargeon and Graber—the one in which infants were habituated to the no-window event and then tested with all three events—multiple differences remain. To list a few, not only did the infants in the two experiments see different events, as should be clear from the descriptions above, but they also received different numbers of trials. Baillargeon and Graber gave their infants four familiarization trials followed by three pairs of test trials, with the two test events shown on alternate trials. In contrast, Bogartz et al. gave their infants 6 to 14 habituation trials followed by three different test trials, one for each test event. In addition, different criteria were used to terminate the trials. For example, Baillargeon and Graber ended a test trial when the infant looked away from the event for 2 consecutive seconds after having looked at it for at least 6 cumulative seconds; because each rabbit took about 7 s to cross the apparatus, the 6-s value helped ensure that the infants had sufficient information to distinguish between the two test events. In contrast, Bogartz et al. terminated a trial when the infant looked away from the event for 2 consecutive seconds after having looked at it for 0.5 cumulative second—despite the fact that the rabbit in their experiment also took about 7 s to cross the apparatus. Any or all the differences listed here could have contributed to the negative results of Bogartz et al.

Rotating screen experiment. Bogartz et al. (2000), Cashon and Cohen (2000), Roder et al. (2000), and Schilling (2000) suggested that the infants in the rotating screen experiments (Baillargeon, 1987; Baillargeon et al., 1985) looked reliably longer at the unexpected event because they were not able to fully process the 180° rotation during the habituation trials, and so preferred this same rotation during the test trials. This account predicts that infants should display the same familiarity preference if tested *without* a box behind the screen. However, as was noted in the last section, this was not the case: infants aged 3.5–5.5 months looked reliably longer at the 180° rotation when a box stood behind the screen, but not otherwise (Baillargeon, 1987; Baillargeon et al., 1985; Durand & Lécuyer, in press; Slater et al., 2004).

Bogartz et al. (2000) and Cashon and Cohen (2000) failed to replicate the experimental and control results just described. If we focus on the conditions that most closely approximated those of the original rotating screen experiments, a clear pattern emerges. In one experiment, Bogartz et al. habituated 5.5-month-old infants to a 180° screen rotation; in another experiment, infants saw the same rotation for seven familiarization trials. Next, all infants received four test trials showing four different events, in random order: a 180° rotation with a box, a 180° rotation without a box, a 120° rotation with a box, and a 120° rotation without a box. Cashon and Cohen tested 8-month-old infants using computer-animated events. As in Bogartz et al., the infants were habituated to a 180° rotation, and then were presented with the four test events just listed. In all three experiments, the same overall pattern was found: the infants tended to look longer at the 120° rotation with a box than at the other three events. In other words, the infants tended to look longer at the event that was perceptually most novel or most different from the habituation or familiarization event.

Because the events and procedures used by Bogartz et al. (2000) and Cashon and Cohen (2000) differed in multiple respects from those of Baillargeon and her colleagues (Baillargeon, 1987; Baillargeon et al., 1985), it is again difficult to draw firm conclusions about the factors responsible for their discrepant results (for discussion, see Aslin, 2000;

Baillargeon, 2000; Munakata, 2000). Nevertheless, one intriguing possibility (which we are planning to test empirically) is that these different experiments in fact tapped different abilities or functional systems. Specifically, it may be that the experiments of Baillargeon (1987) and Baillargeon et al., (1985), Durand and Lécuyer (in press), and Slater et al. (2004) tapped infants' ability to predict and interpret the outcomes of physical events—in other words, to *monitor* events. In contrast, the experiments of Bogartz et al. (2000) and Cashon and Cohen (2000) tapped infants' ability to *recognize* events. Just as familiarity and novelty preferences have been found in infants' ability to recognize objects, depending on age, task complexity, and length of exposure (e.g. Hunter & Ames, 1988; Hunter, Ames, & Koopman, 1983; Hunter, Ross, & Ames, 1982; Roder et al., 2000; Rose, Gottfried, Melloy-Carminar, & Bridger, 1982; Wagner & Sakovits, 1986), similar effects might again be expected in tasks focusing on infants' ability to recognize events. And indeed, Bogartz et al. reported, for example, that infants who received only three familiarization trials with the 180° rotation tended to prefer the 180° over the 120° rotations (with or without a box) during the test trials.

Although further research is needed to determine what factors might lead infants to process events for monitoring as opposed to recognition purposes, one factor immediately comes to mind. Bogartz et al. (2000) and Cashon and Cohen (2000) showed their infants four different test events for one trial each. In contrast, Baillargeon (1987) showed her infants two test events for four trials each (see also Baillargeon et al., 1985; Durand & Lécuyer, in press; Slater et al., 2004). It seems plausible that seeing a different event on every trial might encourage infants to focus on the perceptual similarities and differences between the events, rather than to attempt to predict and interpret their outcomes.[8]

6.3. VOE tasks with anchoring trials

We have argued thus far that (1) infants succeed at some VOE tasks involving hidden objects even when given *no* habituation or familiarization trials; (2) infants may succeed at other VOE tasks *only* when given habituation or familiarization trials that help orient them to the test situation; and (3) when orientation trials are required, researchers must rule out the possibility that infants' surprise at the unexpected test events simply reflects a transient novelty or familiarity preference induced by the orientation trials. In the last section, we considered three such transient-preference accounts, and in each case we reviewed additional findings that did not support the account.

Our discussion so far has thus centered on VOE tasks that do and do not require *orientation* trials prior to the test trials. In this section, we briefly discuss another kind of VOE task: tasks that require *anchoring* trials prior to the test trials. These anchoring trials typically present information that infants with the appropriate knowledge can use to form

[8] This analysis has implications for the experiment of Bogartz et al. (1997) discussed earlier. Recall that the infants were habituated to the no-window event and then shown the no-window, rabbit-appears, and rabbit-does-not-appear event for a single test trial each. Consistent with the present speculations, the infants tended to look longer at the rabbit-appears than at the other two events. Relative to the no-window event, the rabbit-appears event was perceptually more novel than the rabbit-does-not-appear event because it not only involved a window, but also the rabbit was visible for a greater portion of its trajectory.

an expectation about the situation (e.g. an expectation about how many objects are involved in an event, or about which of two potential goal objects an actor prefers). The test events either confirm this expectation (expected event) or violate it (unexpected event).

To illustrate, consider a VOE task (adapted from Spelke, Kestenbaum, Simons, & Wein, 1995a) in which infants are first habituated to a cylinder moving back and forth along a track; at the center of the track are two screens separated by a gap. The cylinder disappears behind one screen and reappears from behind the other screen without ever appearing in the gap between them. Next, the screens are removed, and infants see two test events. One event involves two cylinders, and their trajectories are precisely those required to produce the habituation event (e.g. one cylinder, located at the left end of the track, moves a short distance to the right and stops; next, the other cylinder, located further along the track, moves to the right end of the track; finally, the entire sequence is repeated in reverse). In the other event, a single cylinder moves back and forth along the track. If infants infer, when watching the habituation event, that two cylinders must be involved in the event, then they should look reliably longer at the one- than at the two-cylinder event.

In this VOE task, the habituation trials do not simply serve to orient infants to the test situation. Without these trials, infants—or adults for that matter—would have no basis for viewing either test event as unexpected: both would appear physically possible. The habituation trials thus help *anchor* infants' reasoning about the situation. Infants bring to bear their physical knowledge to develop an expectation about how many cylinders are present behind the screens (two); this expectation in turn allows infants to determine how many cylinders should be revealed when the screens are removed in the test events (two).

Many different VOE tasks involve anchoring trials. For example, in an object segregation task, infants who saw test displays involving a complete rod or a rod with its central portion removed would have no basis for viewing either display as unexpected, unless they first received anchoring trials depicting, for example, a rod with its center hidden by a block (Kellman & Spelke, 1983). Similarly, in a psychological reasoning task, infants who saw an actor reach for a toy bear, on the right, as opposed to a ball, on the left, would have no reason for viewing either of these test events as unexpected, unless they were first given anchoring trials in which the actor consistently preferred the toy bear, on the left, over the ball on the right (Woodward, 1998; see also Gergely et al., 1995). Other examples involve tasks from the object individuation (e.g. Xu & Carey, 1996) and calibration-based reasoning (e.g. Kotovsky & Baillargeon, 1998) literatures.

VOE tasks with anchoring trials are open to the same concerns as VOE tasks with orientation trials. If infants in a VOE task with anchoring trials look reliably longer at the unexpected than at the expected event, how can we be certain that the anchoring trials did not induce a transient novelty or familiarity preference for the unexpected event? The only recourse, once again, must be to conduct control experiments that evaluate specific hypotheses about such preferences.

6.4. Event-general constraints and event-specific expectations

Together, the results of VOE tasks with and without orientation trials provide strong evidence that young infants are able to represent hidden objects. But how should this ability be characterized? Over the past few years, several different accounts have been proposed (e.g. Baillargeon, 2002; Haith & Benson, 1998; Munakata, McClelland, Johnson, & Siegler, 1997; Spelke & Hespos, 2001; Wang et al., in press). All of these accounts agree that young infants' ability to represent and to reason about hidden objects is far more limited than that of older children and adults; however, they disagree widely on the nature of these limitations. Here we briefly summarize our own account.

We have argued that when watching a physical event, infants build a specialized representation of the event that is used to predict and interpret its outcome. All the information included in this *physical representation* is subject to a few event-general constraints, which include *continuity* (e.g. Spelke, 1994; Spelke, Phillips, & Woodward, 1995b). The continuity constraint states that objects exist continuously in time and space. This constraint has many corollaries, such as that objects continue to exist when hidden by nearer objects or surfaces; that stationary objects, whether visible or hidden, exist continuously in time; that moving objects, whether visible or hidden, travel along spatially continuous paths; and that two objects, whether visible or hidden, cannot occupy the same space at the same time.

Early in development, infants' physical representations tend to be impoverished: when representing an event, infants typically include only the *basic* spatial and temporal information about the event. When watching a containment event, for example, infants encode only that an object is being lowered inside a container. This information captures the essence of the event, but leaves out most of its details: whether the container is wider than the object, whether it is taller than the object, whether it is transparent, and so on. With development, infants' physical representations become richer and more detailed. As they form event categories and identify the variables relevant for predicting outcomes within each category, infants begin to include this *variable* information in their physical representations of events. When watching an event, infants first represent the basic information about the event, and use this information to categorize the event. Next, infants access their knowledge of the category selected; this knowledge specifies the variables that have been identified as relevant to the category. Infants then include this variable information in their physical representation of the event. To return to our containment example, infants who have identified the variable width as relevant to containment events would include information about the relative widths of the object and container in their physical representation of the event; infants who have not yet identified width as a containment variable typically would not include this information in their physical representation of the event.

According to the preceding account, violations in VOE tasks involving hidden objects are thus all continuity violations. Infants succeed at detecting a violation in an unexpected event when they include the relevant information in their physical representation of the event, this information becomes subject to the continuity constraint, and the event is tagged as violating the constraint. Whether infants detect a violation in an unexpected event thus crucially depends on whether they include the relevant information in their physical representation of the event.

In line with this analysis, the account distinguishes between two kinds of continuity violations: basic and variable violations. *Basic* violations are those that involve only basic information: in other words, they can be detected as long as the basic information about the events is adequately represented (the basic information becomes subject to the continuity constraint, and the events are marked as violating the constraint). Because young infants are often able to represent the basic information about events, the account predicts that they should be able to detect many continuity violations—specifically, *young infants should succeed in detecting any continuity violation that involves only the basic information they can represent*. And indeed, there are now many reports consistent with this prediction: for example, there is evidence that infants as young as 2.5 months are surprised when an object disappears behind one occluder and reappears from behind another occluder without appearing in the gap between them (Aguiar & Baillargeon, 1999; Wilcox et al., 1996; Luo & Baillargeon, in press); when an object is lowered inside a container which is then moved aside to reveal the object (Hespos & Baillargeon, 2001b); and when a cover is lowered over an object, slid to the side, and lifted to reveal no object (Wang et al., in press).[9]

On the other hand, *variable* violations are those that involve variable information: they can be detected only when the relevant variable information about the events is represented (the variable information becomes subject to the continuity constraint, and the events are tagged as violating the constraint). Because young infants typically do not include information about a variable in their physical representation of an event from a category until they have identified the variable as relevant to the category, the account predicts that they should fail to detect many variable continuity violations—specifically, *young infants should fail to detect any continuity violation that involves variable information they do not yet represent*. Here again, there are now many reports consistent with this prediction: for example, there is evidence that infants younger than 3.5 months are not surprised when a tall object fails to become visible in a screen's high window (Baillargeon & DeVos, 1991; Luo & Baillargeon, in press); that infants younger than 7.5 months are not surprised when a tall object becomes almost completely hidden inside a short container (Hespos & Baillargeon, 2001a); that infants younger than 9.5 months are not surprised when an object becomes hidden inside a transparent container (Luo & Baillargeon, 2004); that infants younger than 12 months are not surprised when a tall object becomes fully hidden under a short cover (Wang et al., in press); and that infants younger than 14 months are not surprised when a tall object becomes fully hidden inside a short tube (Wang et al., in press).

In terms of the present research, the account described here makes a clear prediction: infants younger than 4 months who have not yet identified width as an occlusion or a containment variable, should fail to detect the violations in the experimental narrow-occluder (Experiment 1) and narrow-container (Experiment 2) events. Infants should not be surprised to see a wide object disappear behind a narrow occluder or inside a narrow container, if they do not represent the fact that the object is wider than the occluder or container.

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[9] There are two reports in the literature where young infants failed to detect basic continuity violations, most likely because they could not represent the basic information about the events. One such report involves the car experiment (Baillargeon & DeVos, 1991): 4-month-old female infants detected the violation in the unexpected event but 4-month-old male and 3.5-month-old female infants did not, presumably because their depth perception was too limited to allow them to determine, when the screen was briefly raised, where the box stood in relation to the car's track (e.g. Held, Thorn, Gwiazda, & Bauer, 1996). The other report involves the rotating screen experiment (Baillargeon, 1987): recall that the 3.5-month-old slow habituators failed to detect the violation in the unexpected event, most likely because they could not understand the 180° screen rotation and hence could not represent the basic information about the event.

The present account thus differs from Piaget's (1954) account of the development of object permanence in that it assumes that even very young infants believe that objects continue to exist *after* they become hidden behind occluders, under covers, and inside containers or tubes. On the other hand, our account resembles that of Piaget in that it assumes that infants' ability to represent and to reason about hidden objects develops slowly during the first 2 years of life. In particular, infants are initially very poor at predicting *when* objects behind occluders, under covers, and inside containers or tubes should be hidden. As infants identify the variables relevant to occlusion, covering, containment, and other events involving hidden objects, they come to include information about these variables in their physical representations, which allows them to detect violations involving the variables.

6.5. Concluding remarks

The present experiments provide the first demonstration that young infants can succeed at VOE tasks involving hidden objects when given only test trials—indeed, when given a single test trial. Such a demonstration does not mean, of course, that infants should succeed at all VOE tasks involving hidden objects in the absence of habituation or familiarization trials; such trials may be needed, for example, to orient infants to the test situation and thus help them focus on the key aspects of interest to the investigators. In cases where orientation trials are required, alternative accounts that appeal to transient and superficial preferences induced by these trials must be evaluated experimentally. In this article, we considered three such accounts, and concluded in each case that additional findings did not support them.

In sum, the present research provides further evidence that young infants possess expectations about hidden objects. From a very early age, infants can thus begin to learn about occlusion, containment, and other events involving hidden objects. Although this learning is certainly slow and protracted, as we saw in the last section, there is little doubt that young infants' physical world, like adults', includes both visible and hidden objects.

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References

Aguiar, A., & Baillargeon, R. (1998). Eight-and-a-half-month-old infants' reasoning about containment events. *Child Development*, *69*, 636–653.

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

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

Aguiar, A., & Baillargeon, R. (2003). Perseverative responding in a violation-of-expectation task in 6.5-month-old infants. *Cognition*, *88*, 277–316.

Aslin, R. N. (2000). Why take the cog out of infant cognition? *Infancy*, *1*, 463–470.

Baillargeon, R. (1986). Representing the existence and the location of hidden objects: Object permanence in 6- and 8-month-old infants. *Cognition*, *23*, 21–41.

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

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

Baillargeon, R. (1994a). How do infants learn about the physical world? *Current Directions in Psychological Science*, *3*, 133–140.

Baillargeon, R. (1994b). Physical reasoning in young infants: Seeking explanations for unexpected events. *British Journal of Developmental Psychology*, *12*, 9–33.

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

Baillargeon, R. (1999). Young infants' expectations about hidden objects: A reply to three challenges. *Developmental Science*, *2*, 115–132.

Baillargeon, R. (2000). Reply to Bogartz, Shinskey, and Schilling; Schilling; and Cashon and Cohen. *Infancy*, *1*, 447–462.

Baillargeon, R. (2002). The acquisition of physical knowledge in infancy: A summary in eight lessons. In U. Goswami (Ed.), *Blackwell handbook of childhood cognitive development* (pp. 47–83). Oxford: Blackwell.

Baillargeon, R., & DeVos, J. (1991). Object permanence in young infants: Further evidence. *Child Development*, *62*, 1227–1246.

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

Baillargeon, R., Kotovsky, L., & Needham, A. (1995). The acquisition of physical knowledge in infancy. In D. Sperber, D. Premack, & A. J. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 79–116). Oxford: Clarendon Press.

Baillargeon, R., & Luo, Y. (2002). *Development of the object concept* (*Vol. 3*). *Encyclopedia of cognitive science*, London: Nature, pp. 387–391.

Baillargeon, R., Needham, A., & DeVos, J. (1992). The development of young infants' intuitions about support. *Early Development and Parenting*, *1*, 69–78.

Baillargeon, R., Spelke, E. S., & Wasserman, S. (1985). Object permanence in 5-month-old infants. *Cognition*, *20*, 191–208.

Baillargeon, R., & Wang, S. (2002). Event categorization in infancy. *Trends in Cognitive Sciences*, *6*, 85–93.

Bogartz, R. S., Shinskey, J. L., & Schilling, T. H. (2000). Object permanence in five-and-a half-month-old infants? *Infancy*, *1*, 403–428.

Bogartz, R. S., Shinskey, J. L., & Speaker, C. J. (1997). Interpreting infant looking: The Event Set × Event Set design. *Developmental Psychology*, *33*, 408–422.

Casasola, M., Cohen, L., & Chiarello, E. (2003). Six-month-old infants' categorization of containment spatial relations. *Child Development*, *74*, 679–693.

Cashon, C. H., & Cohen, L. B. (2000). Eight-month-old infants' perception of possible and impossible events. *Infancy*, *1*, 429–446.

Cohen, L. B., & Marks, K. S. (2002). How infants process addition and subtraction events. *Developmental Science*, *5*, 186–212.

Csibra, G., Gergely, G., Biro, S., Koos, O., & Brockbank, M. (1999). Goal attribution without agency cues: The perception of 'pure reason' in infancy. *Cognition*, *72*, 237–267.

Durand, K., & Lécuyer, R (in press). Object permanence observed in four-month-old infants with a 2-D display. *Infant Behavior and Development*.

Gergely, G., Nadasdy, Z., Csibra, G., & Biro, S. (1995). Taking the intentional stance at 12 months of age. *Cognition*, *56*, 165–193.

Goubet, N., & Clifton, R. K. (1998). Object and event representation in 6.5-month-old infants. *Developmental Psychology*, *34*, 63–76.

Haith, M. M., & Benson, J. B. (1998). Infant cognition. In W. Damon (Series Ed.), D. Kuhn, & R. Siegler (Vol. Eds.) (Eds.), *Handbook of child psychology: Vol. 2. Cognition, perception, and language* (5th ed.) (pp. 199–254). New York: Wiley.

Harris, P. L. (1987). The development of search. In P. Salapatek, & L. B. Cohen (Eds.), (*Vol. 2*) (pp. 155–207). *Handbook of infant perception*, New York: Academic Press.

Held, R., Thorn, F., Gwiazda, J., & Bauer, J. (1996). Development of binocularity and its sex differentiation. In F. Vital-Durand, & J. Atkinson (Eds.), (pp. 265–274). *The European brain and behaviour society series: Vol. 2 Infant vision*, Cambridge, MA: MIT Press.

Hespos, S. J., & Baillargeon, R. (2001a). Infants' knowledge about occlusion and containment events: A surprising discrepancy. *Psychological Science*, *12*, 140–147.

Hespos, S. J., & Baillargeon, R. (2001b). Knowledge about containment events in very young infants. *Cognition*, *78*, 204–245.

Hespos, S. J., & Baillargeon, R. (2004). *Decalage in infants' reasoning about occlusion and containment events: Converging evidence from action tasks*. Manuscript in preparation.

Hofstadter, M., & Reznick, J. S. (1996). Response modality affects human infant delayed-response performance. *Child Development*, *67*, 646–658.

Hood, B., & Willatts, P. (1986). Reaching in the dark to an object's remembered position: Evidence of object permanence in 5-month-old infants. *British Journal of Developmental Psychology*, *4*, 57–65.

Hunter, M. A., & Ames, E. W. (1988). A multifactor model of infant preferences for novel and familiar stimuli. In C. Rovee-Collier, & L. P. Lipsitt (Eds.), (*Vol. 5*) (pp. 69–95). *Advances in infancy research*, Norwood, NJ: Ablex.

Hunter, M. A., Ames, E. W., & Koopman, R. (1983). Effects of stimulus complexity and familiarization time on infant preferences for novel or familiar stimuli. *Developmental Psychology*, *19*, 338–352.

Hunter, M. A., Ross, H. S., & Ames, E. W. (1982). Preferences for familiar or novel toys: Effects of familiarization time in 1-year-olds. *Developmental Psychology*, *18*, 519–529.

Johnson, S. P. (1997). Young infants' perception of object unity: Implications for development of attentional and cognitive skills. *Current Directions in Psychological Science*, *6*, 5–11.

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

Koechlin, E., Dehaene, S., & Mehler, J. (1998). Numerical transformation in five-month-old infants. *Mathematical Cognition*, *3*, 89–104.

Kotovsky, L., & Baillargeon, R. (1998). The development of calibration-based reasoning about collision events in young infants. *Cognition*, *67*, 311–351.

Lécuyer, R., & Durand, K. (1998). Bi-dimensional representations of the third dimension and their perception by infants. *Perception*, *27*, 465–472.

Leslie, A. M. (1995). A theory of agency. In D. Sperber, D. Premack, & A. J. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 121–149). Oxford, UK: Clarendon Press.

Luo, Y., & Baillargeon, R. (2004). *Infants' reasoning about events involving transparent containers*. Manuscript in preparation.

Luo, Y., & Baillargeon, R. (2004). *When the ordinary seems unexpected: Evidence for rule-based reasoning in young infants*. *Cognition*, in press.

Luo, Y., Baillargeon, R., Brueckner, L., & Munakata, Y. (2003). Reasoning about a hidden object after a delay: Evidence for robust representations in 5-month-old infants. *Cognition*, *88*, B23–B32.

Luo, Y., Baillargeon, R., & Lécuyer, R. (2004). *Young infants' reasoning about height in occlusion events*. In press.

McDonough, L., Choi, S., & Mandler, J. M. (2003). Understanding spatial relations: Flexible infants, lexical adults. *Cognitive Psychology*, *46*, 229–259.

Munakata, Y. (2000). Challenges to the violation-of-expectation paradigm: Throwing the conceptual baby out with the perceptual processing bathwater? *Infancy*, *1*, 471–490.

Munakata, Y., McClelland, J. L., Johnson, M. H., & Siegler, R. (1997). Rethinking infant knowledge: Toward an adaptive process account of successes and failures in object permanence tasks. *Psychological Review*, *104*, 686–713.

Needham, A. (1998). Infants' use of featural information in the segregation of stationary objects. *Infant Behavior and Development*, *21*, 47–76.

Needham, A., & Ormsbee, S. M. (in press). The development of object segregation during the first year of life. In R. Kimchi, M. Behrmann, & C. Olson (Eds.), *Perceptual organization in vision: Behavioral and neural perspectives*. Mahwah, NJ: Erlbaum.

Newcombe, N., Huttenlocher, J., & Learmonth, A. (1999). Infants' coding of location in continuous space. *Infant Behavior and Development*, *22*, 483–510.

Piaget, J. (1952). *The origins of intelligence in children*. New York: International Universities Press.

Piaget, J. (1954). *The construction of reality in the child*. New York: Basic Books.

Rivera, S. M., Wakeley, A., & Langer, J. (1999). The drawbridge phenomenon: Representational reasoning or perceptual preference? *Developmental Psychology*, *35*, 427–435.

Roder, B. J., Bushnell, E. W., & Sasseville, A. M. (2000). Infants' preferences for familiarity and novelty during the course of visual processing. *Infancy*, *1*, 491–507.

Rose, S. A., Gottfried, A. W., Melloy-Carminar, P., & Bridger, W. H. (1982). Familiarity and novelty preferences in infant recognition memory: Implications for information processing. *Developmental Psychology*, *18*, 704–713.

Schilling, T. H. (2000). Infants' looking at possible and impossible screen rotations: The role of familiarization. *Infancy*, *1*, 389–402.

Sitskoorn, S. M., & Smitsman, A. W. (1995). Infants' perception of dynamic relations between objects: Passing through or support? *Developmental Psychology*, *31*, 437–447.

Slater, A., Hayes, R., Quinn, P. C., Haldorsson, A., & Brown, E. (2004). *The drawbridge phenomenon revisited: The case for representational reasoning*. Manuscript in preparation.

Spelke, E. S. (1991). Principles of object perception. *Cognitive Science*, *14*, 29–56.

Spelke, E. S. (1994). Initial knowledge: Six suggestions. *Cognition*, *50*, 431–445.

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

Spelke, E. S., & Hespos, S. (2001). Continuity, competence, and the object concept. In E. Dupoux (Ed.), *Language, brain, and cognitive development: Essays in honor of Jacques Mehler* (pp. 325–340). Cambridge, MA: MIT Press.

Spelke, E. S., Kestenbaum, R., Simons, D. J., & Wein, D. (1995a). Spatiotemporal continuity, smoothness of motion, and object identity in infancy. *British Journal of Developmental Psychology*, *13*, 130.

Spelke, E. S., Phillips, A., & Woodward, A. L. (1995b). Infants' knowledge of object motion and human action. In D. Sperber, D. Premack, & A. J. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 44–78). Oxford, UK: Clarendon Press.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge, MA: MIT Press.

Wagner, S. H., & Sakovits, L. J. (1986). A process analysis of infant visual and cross-modal recognition memory: Implications for an amodal code. In L. P. Lipsitt, & C. Rovee-Collier (Eds.), (*Vol. 4*) (pp. 195–217). *Advances in infancy research*, Norwood, NJ: Ablex.

Wang, S., Baillargeon, R., & Paterson, S (in press). Detecting continuity and solidity violations in infancy: A new account and new evidence from covering events. *Cognition*.

Wang, S., Kaufman, L., & Baillargeon, R. (2003). Should all stationary objects move when hit? Developments in infants' causal and statistical expectations about collision events [Special issue]. *Infant Behavior and Development*, *26*, 529–568.

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

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

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

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

Wilcox, T., & Schweinle, A. (2003). Infants' use of speed information to individuate objects in occlusion events. *Infant Behavior and Development*, *26*, 253–282.

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition*, *69*, 1–34.

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

Wynn, K. (2002). Do infants have numerical expectations or just perceptual preferences? *Developmental Science*, *5*, 207–209.

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

Yonas, A., & Granrud, C. E. (1984). The development of sensitivity to kinetic, binocular, and pictorial depth information in human infants. In D. Engle, D. Lee, & M. Jeannerod (Eds.), *Brain mechanisms and spatial vision* (pp. 113–145). Dordrecht: Martinus Nijhoff.