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When the ordinary seems unexpected: evidence for incremental physical knowledge in young infants

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Abstract

According to a recent account of infants' acquisition of their physical knowledge, the *incremental-knowledge* account, infants form distinct event categories, such as occlusion, containment, support, and collision events. In each category, infants identify one or more vectors which correspond to distinct problems that must be solved. For each vector, infants acquire a sequence of variables that enables them to predict outcomes within the vector more and more accurately over time. This account predicts that infants who have acquired only a few of the variables in a sequence should err in two ways in violation-of-expectation tasks: (1) they should view impossible events consistent with their incomplete knowledge as expected (errors of omission), and (2) they should view possible events inconsistent with their incomplete knowledge as unexpected (errors of commission). Many reports have shown that infants who have not yet identified a variable in an event category produce errors of omission: they fail to view impossible events involving the variable as unexpected. However, there has been no report revealing errors of commission in infants' responses to possible events. The present research examined whether 3- and 2.5-month-old infants, whose knowledge of occlusion events is very limited, would produce errors of commission as well as errors of omission when responding to these events. At 3 months of age, infants viewed as unexpected a possible event in which a tall cylinder became visible when passing behind a tall screen with a very large opening extending from its upper edge. At 2.5 months, infants viewed as unexpected a possible event in which a tall cylinder became visible when passing behind a tall screen with a very large opening extending from its lower edge. These findings provide a new kind of evidence for the incremental-knowledge account, and more generally for the notion that infants, like older children and adults, engage in rule-based reasoning about physical events.

Keywords: Rule-based reasoning in infancy; Occlusion events; Errors of omission and commission

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1. Introduction

As adults, we possess a great deal of knowledge about the physical world: for example, we realize that a tall object cannot become fully hidden behind a short occluder, that a wide object cannot be lowered inside a narrow container, that an object typically falls when only a small portion of its bottom surface is supported, and that an object is typically displaced farther when hit by a larger as opposed to a smaller object. Research over the past 15 years suggests that infants acquire these and many other similar expectations during the first year of life (for recent reviews, see Baillargeon, 2002, 2004). How do they do so?

In the next section, we briefly present a recent account of infants' acquisition of their physical knowledge; we refer to this account as the *incremental-knowledge* account (e.g. Baillargeon, 2001, 2002; Wang, Baillargeon, & Paterson, in press). Next, we derive novel predictions from the account. We then illustrate the account and its predictions using recent research on very young infants' knowledge about occlusion events; the present research was designed to test these predictions.

1.1. The incremental-knowledge account

According to the incremental-knowledge account, infants form distinct *event categories*, such as occlusion, containment, and collision events (e.g. Aguiar & Baillargeon, 2003; Casasola, Cohen, & Chiarello, 2003; Hespos & Baillargeon, 2001a; Luo & Baillargeon, 2005b; McDonough, Choi, & Mandler, 2003; Munakata, 1997; Needham & Ormsbee, 2003; Spelke & Hespos, 2002; Wang et al., in press; Wilcox & Chapa, 2002; for a partial review, see Baillargeon & Wang, 2002). These categories often capture distinct spatial or mechanical relations between objects: for example, an object *behind* a nearer object (occlusion), an object *inside* a container (containment), and an object *hitting* another object (collision) (e.g. Keil, 1995; Leslie, 1995; Pauen, 1999; Quinn, 1994).

In each event category, infants must learn to solve one or more problems in order to correctly predict outcomes within the category; we refer to such problems as *vectors*. For example, in the case of occlusion events, infants must learn to predict whether an object will be fully or only partly hidden when behind an occluder, and also how soon an object that moves behind an occluder will emerge from behind it; in the case of containment events, infants must learn to predict whether an object can be lowered inside a container, and also how much of an object lowered inside a container will protrude above it; and in the case of collision events, infants must learn to predict whether an object is likely to move when hit, and also how far it is likely to move (e.g. Arterberry, 1997; Aguiar & Baillargeon, 1999; Hespos & Baillargeon, 2001b; Kotovsky & Baillargeon, 2000; Oakes & Cohen, 1995; Sitskoorn & Smitsman, 1995; Spelke, Kestenbaum, Simons, & Wein, 1995a; Wang, Baillargeon, & Brueckner, 2004; Wang, Kaufman, & Baillargeon, 2003; Wilcox & Schweinle, 2003).

For each vector in an event category, infants identify a sequence of *variables* that enables them to predict outcomes within the vector more and more accurately over time (e.g. Aguiar & Baillargeon, 2002; Baillargeon, Needham, & Devos, 1992; Dan, Omori, & Tomiyasu, 2000; Hespos & Baillargeon, 2001a; Huettel & Needham, 2000; Kotovsky & Baillargeon, 1998; Luo & Baillargeon, 2005a; Sitskoorn & Smitsman, 1995;

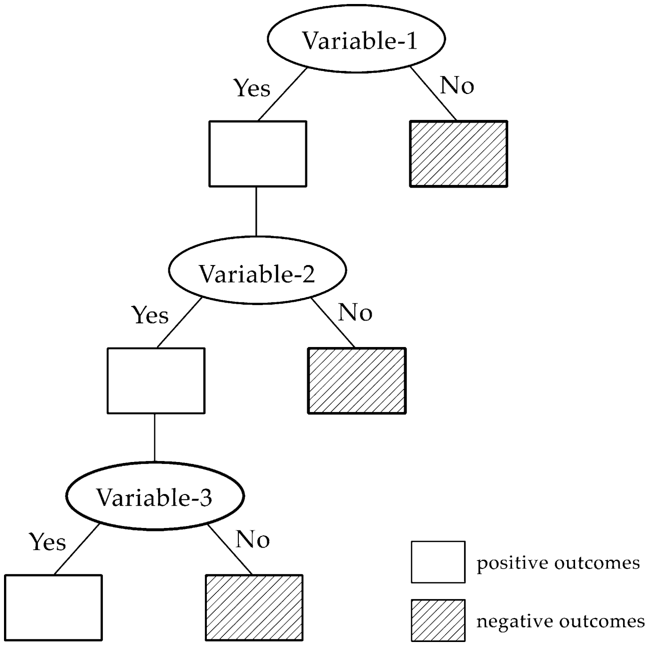

Fig. 1. Schematic decision tree representing infants' identification of a sequence of variables in a vector of an event category.

Wang et al., in press; Wilcox, 1999). Variables are akin to condition-outcome rules: for a set of contrastive outcomes, a variable specifies what condition produces each outcome (for a discussion of how variables are identified, see Baillargeon, 2002, 2004). Each variable that is added along a vector revises and refines predictions from earlier variables. This process is illustrated by the simple decision tree depicted in Fig. 1 (for related ideas, see Mitchell, 1997; Quinlan, 1993; Siegler, 1978). Here we focus on vectors associated with two contrastive outcomes. Examples of such vectors are whether objects behind occluders should be hidden or visible, whether objects can or cannot be lowered through the openings of containers, and whether objects are likely to move or remain stationary when hit. For ease of description, the contrastive outcomes are arbitrarily labeled as positive (e.g. objects should be hidden) and negative (e.g. objects should be visible); the condition of a variable that predicts positive outcomes will be referred to as the positive condition, and the condition that predicts negative outcomes as the negative condition.

As shown in Fig. 1, infants' initial variable represents a first cut: events that satisfy the positive condition of the variable are now expected to lead to positive outcomes, and events that satisfy the negative condition to negative outcomes. New variables introduce additional partitions. In the decision tree shown in Fig. 1, the next variable in the vector involves the events associated with positive outcomes: whereas events that satisfy the positive condition of the new variable are still expected to lead to positive outcomes, events that satisfy the negative condition of the new variable are now expected to lead to negative outcomes. The next variable operates in the same way, again introducing a partition among the events previously associated with positive outcomes.

The decision tree shown in Fig. 1 represents only one possible tree. Other trees might involve, for example, partitions of both the positive and negative outcomes, with branches proliferating on both sides of the tree. But the decision tree in Fig. 1 is sufficient for present purposes: it illustrates the fact that, for each vector in an event category, infants identify a sequence of variables that enables them to predict outcomes more and more accurately over time. With each new variable—or each additional partition in the decision tree—infants' predictions about events' outcomes slowly approximate those of older children and adults.

1.2. Errors of omission and commission

Most of the evidence for the incremental-knowledge account described in the last section has come from violation-of-expectation (VOE) tasks (for exceptions, see Casasola et al., 2003; Hespos & Baillargeon, 2005, in press; McCall, 2001; McDonough et al., 2003). The rationale of the VOE method is that infants typically look reliably longer at events that are inconsistent (*unexpected* events), as opposed to consistent (*expected* events), with their expectations.

To determine whether infants have identified a variable in a vector of an event category, researchers typically use VOE tasks involving a physically *possible* event consistent with the variable and a physically *impossible* event inconsistent with the variable. Both events usually have the same outcome (i.e. both positive or both negative), to minimize superficial differences between the events.

For example, to ascertain whether infants have identified Variable-3 in Fig. 1, researchers might use the following events: a possible event which satisfies the positive condition of Variable-3 and has a positive outcome, and an impossible event which satisfies the negative condition of Variable-3 and yet also has a positive outcome. Alternatively, infants might be shown a possible event which satisfies the negative condition of Variable-3 and has a negative outcome, and an impossible event which satisfies the positive condition of Variable-3 but has a negative outcome. In either case, infants who *have* identified Variable-3 should view the possible event as expected and the impossible event as unexpected, and they should therefore look reliably longer at the impossible than at the possible event.

Infants who have identified Variable-2, but have *not* yet identified Variable-3, should expect all events that satisfy the positive condition of Variable-2 to have positive outcomes. As a result, infants should systematically err in their responses to events that (also) satisfy the negative condition of Variable-3: (1) they should view as expected impossible events that satisfy the negative condition of Variable-3 and yet have a positive outcome; and (2) they should view as unexpected possible events that satisfy the negative condition of Variable-3 and have a negative outcome. In this article, we refer to the first kind of error–viewing an impossible event as expected—as an error of *omission*, and to the second kind of error–viewing a possible event as unexpected—as an error of *commission*.

According to the incremental-knowledge account, infants who have not yet identified a variable in a vector of an event category should thus produce both errors of omission and errors of commission in their responses to events involving the variable.

To date, many investigations of infants' physical knowledge have revealed errors of omission: infants who have not yet identified a variable in a vector of an event category typically do not view impossible events involving the variable as unexpected (e.g. Aguiar & Baillargeon, 1999; Baillargeon & Devos, 1991; Baillargeon et al., 1992; Dan et al., 2000; Hespos & Baillargeon, 2001a; Huettel & Needham, 2000; Kotovsky & Baillargeon, 1998; Sitskoorn & Smitsman, 1995; Wang et al., in press; Wilcox, 1999). However, there has been *no* report revealing errors of commission in infants' responses to possible events: investigators have generally presented infants with possible events consistent, rather than inconsistent, with their faulty knowledge (e.g. infants who have identified Variable-2 but not Variable-3 in Fig. 1 will view as expected possible events that satisfy the positive condition of Variable-3 and have a positive outcome). The present research examined whether 3- and 2.5-month-old infants, whose knowledge of *occlusion* events is very limited, would produce errors of commission as well as errors of omission when responding to these events.

1.3. Young infants' responses to occlusion events

Spelke and her colleagues have proposed that infants' responses to occlusion and other physical events are guided by a core principle of continuity, which states that objects exist and move continuously in time and space (e.g. Carey & Spelke, 1994; Spelke, 1994; Spelke et al., 1992; Spelke, Phillips, & Woodward, 1995b). In line with this proposal, we have suggested that, when watching an occlusion event, infants build a specialized physical representation of the event; the information included in this representation becomes subject to the continuity principle, and is used to predict and interpret the event's outcome (e.g. Baillargeon, 2002, 2004; Wang et al., in press). In the first months of life, the information infants include in their physical representations of occlusion events tends to be very sparse. Thus, although 2.5-month-old infants recognize that an object continues to exist *after* it becomes hidden behind an occluder (e.g. Aguiar & Baillargeon, 1999; Spelke et al., 1992; Wilcox, Nadel, & Rosser, 1996), they are very poor at predicting *when* an object behind an occluder should be hidden, *how soon* an object should reappear from behind an occluder, or *how long* an object should take to cross an opening in an occluder (e.g. Arterberry, 1997; Aguiar & Baillargeon, 2002; Baillargeon & Devos, 1991; Baillargeon & Graber, 1987; Baillargeon & Luo, 2002; Hespos & Baillargeon, 2001a; Luo & Baillargeon, 2005a; Oakes & Cohen, 1995a; Spelke et al., 1995a; Wilcox, 1999; Wilcox & Schweinle, 2003). Predictions steadily improve during the first year as infants identify relevant variables and begin to include information about these variables in their physical representations of occlusion events (for further discussion, see Wang et al., in press).

Three series of experiments have examined 2.5- and 3-month-old infants' ability to predict *when* an object behind an occluder should and should not be hidden (Aguiar & Baillargeon, 1999, 2002; Baillargeon & Devos, 1991). We first summarize the results of these experiments, and then describe the sequence of variables suggested by these results.

In one series of experiments, 3- and 3.5-month-old infants were habituated to events in which a tall or a short toy carrot moved back and forth along a track whose center was hidden by a screen (Baillargeon & Devos, 1991); the carrot disappeared at one edge of the track and reappeared, after an appropriate interval, at the other edge. Following habituation, a large window was created in the screen's upper half and the infants saw a possible and an impossible test event (see Fig. 2(a)). In the possible event, the short carrot moved back and forth behind the screen; this carrot was shorter than the bottom of the window and did not become visible when passing behind the screen. In the impossible event, the tall carrot moved back and forth behind the screen; this carrot should have appeared in the window, but did not in fact do so. The 3.5-month-old infants looked reliably longer at the impossible than at the possible event, suggesting that they viewed the impossible but not the possible event

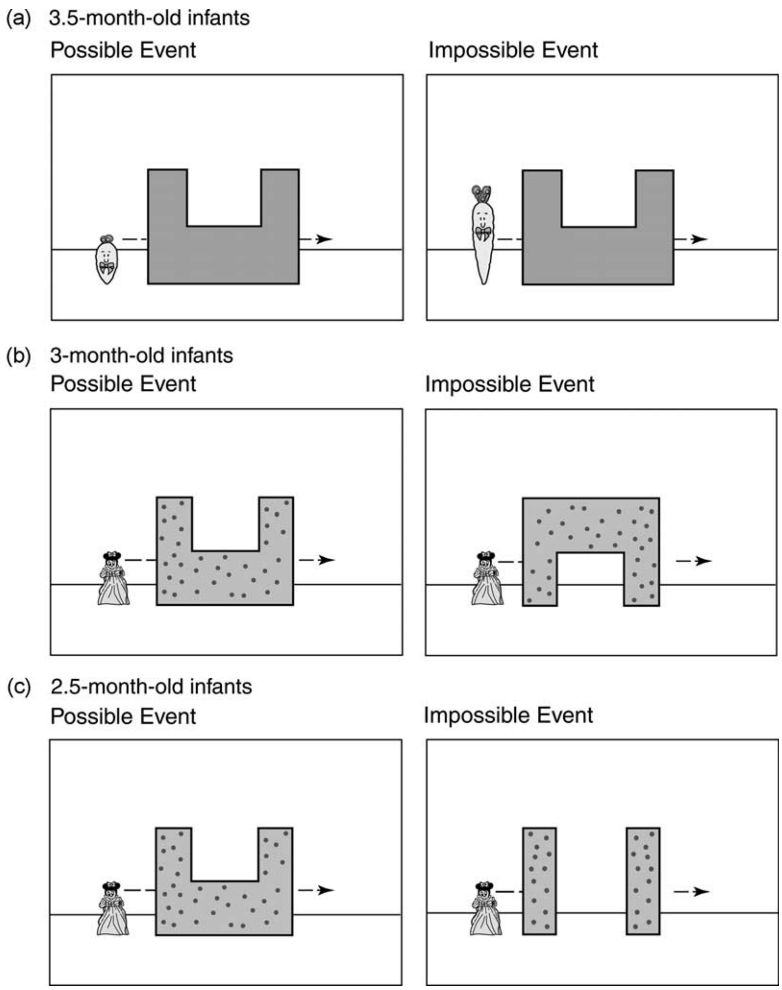

Fig. 2. Schematic drawings of possible and impossible occlusion events infants view as expected and unexpected, respectively, at 3.5 months (Baillargeon & Devos, 1991), 3 months (Aguiar & Baillargeon, 2002), and 2.5 months (Aguiar & Baillargeon, 1999).

as unexpected; the 3-month-old infants tended to look equally at the two events, suggesting that they viewed both events as expected.

In another series of experiments, 3- and 2.5-month-old infants were habituated to a short toy mouse that moved back and forth behind a screen (Aguiar & Baillargeon, 1999, 2002). Following habituation, the infants again saw a possible and an impossible test event (see Fig. 2(b)). In the possible event, as in the previous experiments, a large window was created in the screen's upper half; the mouse was shorter than the bottom of the window and did not become visible when passing behind the screen. In the impossible event, the window was located in the screen's lower half; in this event, the mouse should have appeared in the window but failed to do so. The 3-month-old infants looked reliably longer

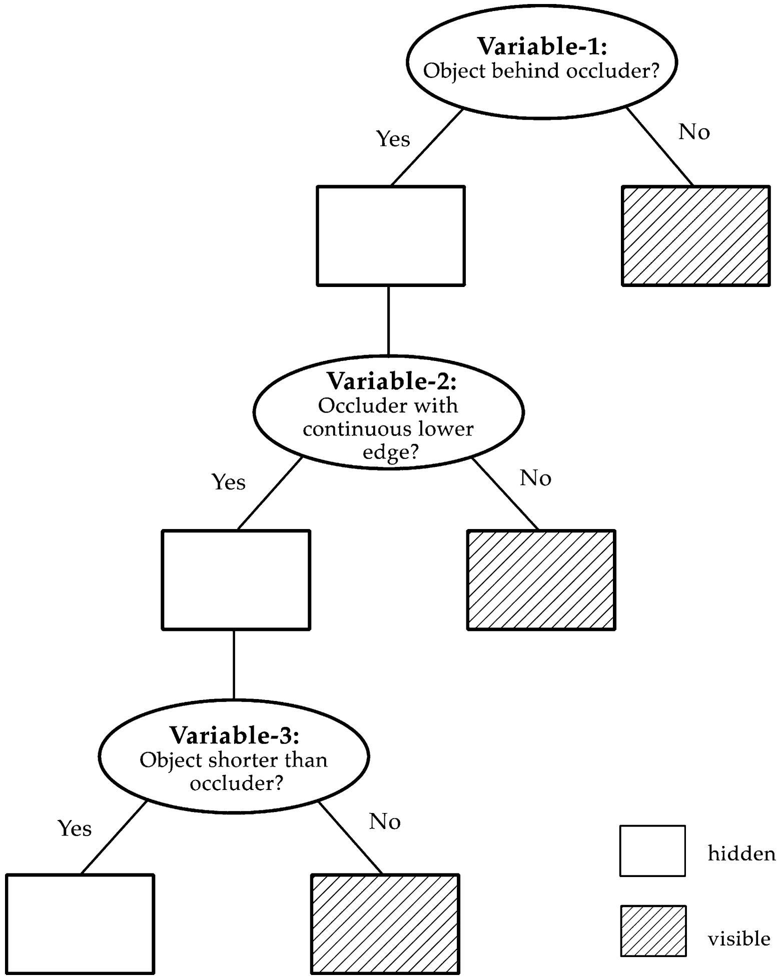

Fig. 3. Schematic decision tree representing the sequence of variables very young infants identify to predict when objects behind occluders should be hidden or visible (Aguiar & Baillargeon, 2002).

at the impossible than at the possible event, but the 2.5-month-old infants tended to look equally at the two events.

In the last series of experiments (Aguiar & Baillargeon, 1999), 2.5-month-old infants saw the same habituation and test events as in the last experiments, with one exception: in the impossible event, the entire midsection of the screen was removed, leaving two screens separated by a gap; the mouse failed to appear in the gap between the screens (see Fig. 2(c)). The infants looked reliably longer at the impossible than at the possible event.

Based on these and additional results, Aguiar and Baillargeon (2002) proposed the following developmental sequence, illustrated by the decision tree in Fig. 3. At 2.5 months of age, infants use only a simple *behind/not-behind* variable to predict when objects behind occluders should be hidden: they expect an object to be hidden when behind an occluder and to be visible when not. Thus, in the impossible event depicted in Fig. 2(c), infants expect the mouse to be hidden when behind each screen but to be visible when between them, because at that point the mouse does not lie behind any occluder. However, in the impossible events depicted in Fig. 2(a) and (b), infants expect the carrot or mouse to remain hidden when behind the screen: at this age, any object is expected to be hidden when behind any occluder. At about 3 months of age, infants identify a new occlusion variable, *lower-edge-discontinuity*: when an object passes behind an occluder whose lower edge is continuous with the surface on which it rests, infants expect the object to remain hidden; however, when an object passes behind an occluder whose lower edge is discontinuous with the surface on which it rests, thus creating an opening, infants expect the object to become visible in that opening. Infants can thus detect the violation shown in Fig. 2(b), but they still cannot detect that in Fig. 2(a). It is not until infants are about 3.5 months of age that they identify *height* as an occlusion variable: they now expect an object behind an occluder to be hidden if it is shorter than the occluder, but to be visible if it is taller than the occluder. Infants thus realize, when shown the impossible event in Fig. 2(a), that the tall carrot is taller than the bottom of the window and hence should become visible when passing behind the screen.[1]

[1] Readers might wonder why infants would identify lower-edge-discontinuity before height as an occlusion variable. One possibility, suggested by Aguiar and Baillargeon (2002), is that lower-edge-discontinuity is identified sooner simply because it is less complex. As adults, from simply knowing that an object is approaching an occluder with a discontinuous lower edge, we can predict that the object will appear in the opening (as long, of course, as the object and occluder rest on the same horizontal plane; a flying object might pass above the opening). Thus, in order to identify the variable lower-edge-discontinuity, infants do not need to encode any information about the *objects* that move behind the occluders. Infants only need to encode information about the *occluders*–whether or not they have a discontinuous lower edge–and to relate this information to the observed outcomes (e.g. "if the occluder has a discontinuous lower edge, the object becomes visible when passing behind this opening; if not, it does not"). In the case of the height variable, however, the relevant conditions are somewhat more complex. Infants must encode information about *both* the objects and occluders. Specifically, infants must compare the relative heights of the objects and occluders, and relate this information to the observed outcomes (e.g. "if the object is taller than the occluder, it remains visible above the occluder; if not, it does not"). It seems reasonable that variables that require gathering and processing more complex information would be harder to identify and hence would be learned later.

1.4. The present research

The present research built on the developmental sequence proposed by Aguiar and Baillargeon (2002). This sequence was entirely suggested by errors of *omission* in infants' responses to occlusion events: infants were shown various impossible events in which objects failed to appear in occluder openings, and with development they came to view more and more of these impossible events as unexpected. However, this same sequence predicts that infants should also make errors of *commission* in their responses to occlusion events: infants should view possible events in which an object appears in an occluder opening as unexpected, when their limited knowledge of occlusion suggests that the object should have remained hidden. The present research examined two such predictions.

Experiment 1 tested whether 3-month-old infants would view as unexpected a possible event in which a tall object became visible when passing behind a tall screen with a continuous lower edge and a very large opening extending from its upper edge. Recall that at this age infants have identified lower-edge-discontinuity but not height as an occlusion variable: they expect an object to remain hidden when behind an occluder with a continuous lower edge, regardless of whether the object is taller or shorter than (any portion of) the occluder.

Experiment 2 examined whether 2.5-month-old infants would view as unexpected a possible event in which an object became visible when passing behind a screen with a very large opening extending from its lower edge. Recall that at this age infants use only a simple behind/not-behind variable: they expect an object to remain hidden when behind an occluder with a continuous or a discontinuous lower edge.

We reasoned that finding errors of commission in Experiments 1 and 2 would be important for three reasons. First, such results would confirm the developmental sequence proposed by Aguiar and Baillargeon (2002), based on the errors of omission they observed. Second, infants' errors of commission would provide a new kind of evidence for the incremental-knowledge account. If infants identify a sequence of variables or rules for each vector in an event category, then it should be the case that, when this sequence is still incomplete, infants err when confronted with possible events—even ordinary and commonplace events—that happen to contradict their faulty knowledge. Like some of young children's speech errors (e.g. "he goed", "she eated"; e.g. Marcus, Pinker, Ullman, Hollander, Rosen, & Xu, 1992), infants' errors of commission when responding to possible events would thus provide strong support for the acquisition of abstract generalizations or rules.

Third, infants' errors of commission would cast doubt on recent alternative accounts of VOE findings (e.g. Bogartz, Shinskey, & Speaker, 1997; Haith, 1998, 1999; Thelen & Smith, 1994). According to these accounts, infants in VOE tasks compare the events before them to similar events they have experienced previously (either in or out of the laboratory), and respond with increased attention when they detect mismatches between the events. For example, Haith (1999) suggested that infants in VOE tasks "detect a mismatch with similar remembered events, resulting in longer looking" (p. 155). In a similar vein, Bogartz et al. (1997) offered a "modifiable videotape metaphor" (p. 411). According to this metaphor, infants form "videotapes" of events and store them in a "library". When watching an event in a VOE task, infants search their library, retrieve the closest videotape, and compare the current and stored events; mismatches result in increased attention. Finally, Thelen and Smith (1994) proposed that infants who watch an event repeatedly 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 respond with increased attention to events that initially follow, but then deviate from, the predicted trajectory. These various *comparison* accounts could not easily explain why infants would respond with increased attention to possible, as opposed to impossible, events. For how could mismatches arise between ordinary possible events and previously stored everyday events? Thus, whereas the incremental-knowledge account predicts that infants should respond with increased attention to possible events, when these happen to contradict their limited physical knowledge, comparison accounts suggest that such responses should be unlikely.

2. Experiment 1

The 3-month-old infants in Experiment 1 saw two test events in which a tall cylinder moved back and forth behind a tall screen with a very large opening in its midsection; a short strip remained above the opening in the discontinuous-lower-edge event, and below the opening in the continuous-lower-edge event. For half of the infants, the cylinder did not appear in the opening in either event (CDNA condition; see Fig. 4); for the other infants, the cylinder appeared (CA condition; see Fig. 5). Prior to the test trials, all of the infants received familiarization trials in which they saw the cylinder move back and forth behind a full screen with no opening in its midsection. Next, the infants received two display trials in which they saw the cylinder standing motionless next to the screen with the discontinuous (discontinuous-lower-edge display) or continuous (continuous-lower-edge display) lower edge. The familiarization and display trials served to acquaint the infants with the cylinder and its motion, and with the two screens used in the test trials.

The infants in the CDNA condition were shown two *impossible* test events. Because at 3 months infants have identified lower-edge-discontinuity but not height as an occlusion variable, we predicted that the infants would view only one of these events as unexpected. Specifically, the infants should view the event in which the cylinder failed to appear behind the screen with a discontinuous lower edge as unexpected (a correct response), but they should view the event in which the cylinder failed to appear behind the screen with a continuous lower edge as expected (an error of omission). The infants should therefore look reliably longer at the discontinuous- than at the continuous-lower-edge event.

Unlike the infants in the CDNA condition, those in the CA condition were shown two *possible* test events. Again, because 3-month-old infants have identified lower-edge-discontinuity but not height as an occlusion variable, we predicted that the infants would view only one of those events as expected. Specifically, the infants should view the event in which the cylinder appeared behind the screen with a discontinuous lower edge as expected (a correct response), but they should view the event in which the cylinder appeared behind the screen with a continuous lower edge as unexpected (an error of commission). The infants should therefore look reliably longer at the continuous- than at the discontinuous-lower-edge event. Opposite patterns of looking were thus predicted for the two conditions.

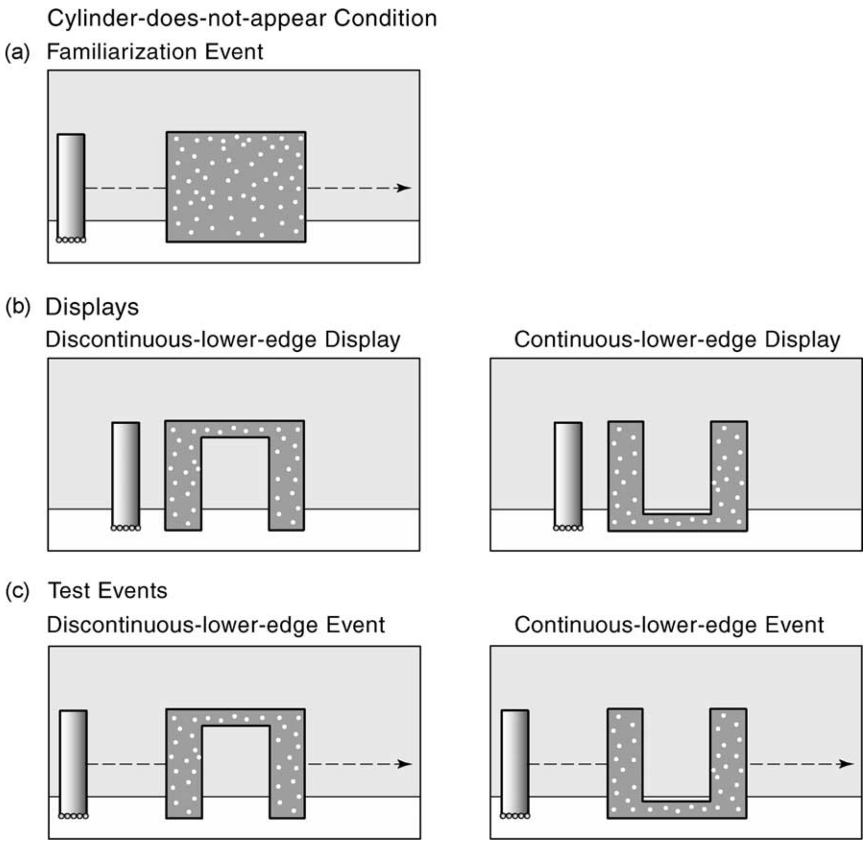

Fig. 4. Schematic drawing of the familiarization event, displays, and test events in the cylinder-does-not-appear (CDNA) condition of Experiment 1.

2.1. Method

2.1.1. Participants

Participants were 16 healthy term infants, 8 male and 8 female (range = 97 to 103 days, M = 99.4 days). Eight infants, 4 male and 4 female, were randomly assigned to the CDNA and CA conditions. Another 14 infants were tested but eliminated, because they looked the maximum amount of time allowed (60 s) on both test trials (6), or because of fussiness (4), inattentiveness (2), or parental interference (2).[2]

[2] The large proportion of eliminated subjects in this and the following experiment is typical of research with very young infants (e.g. Aguiar & Baillargeon, 1999, 2002; Baillargeon & Devos, 1991; Canfield & Haith, 1991; Haith & McCarty, 1990; Hespos & Baillargeon, 2001b). For example, Aguiar and Baillargeon (2002, Experiments 5 and 6) tested 24 3-month-old infants, and eliminated 25 additional infants. Similarly, Aguiar and Baillargeon (1999, Experiments 1-3) tested 80 2.5-month-old infants, and eliminated 78 additional infants.

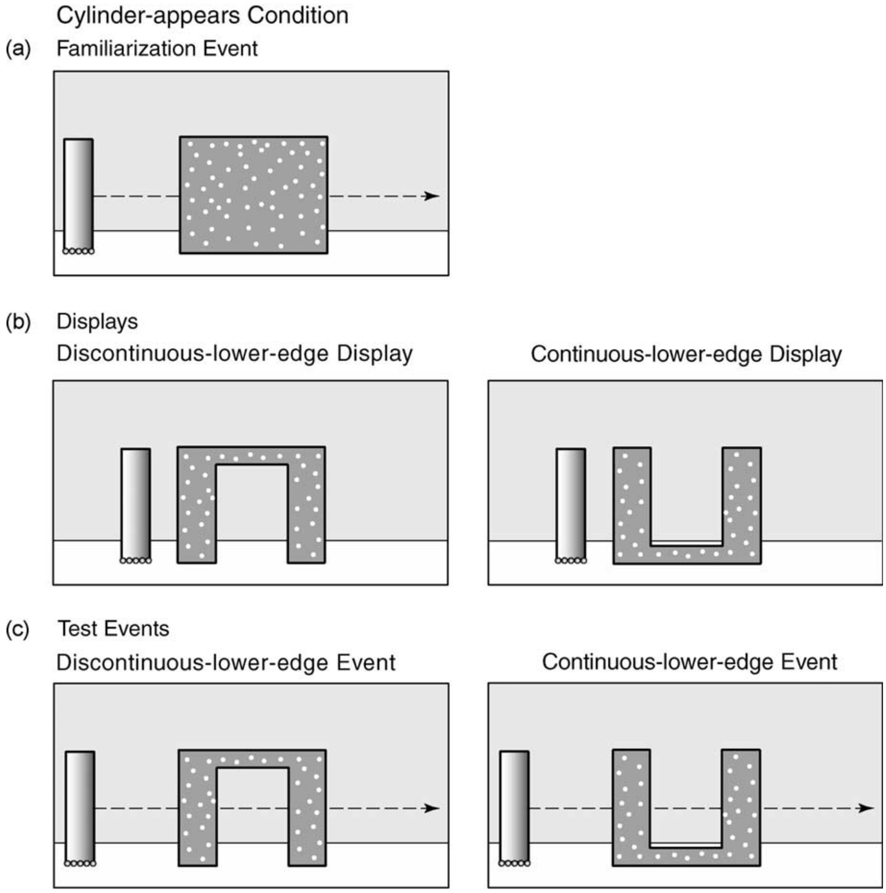

Fig. 5. Schematic drawing of the familiarization event, displays, and test events in the cylinder-appears (CA) condition of Experiment 1.

The infants' names in this and in the following experiment were obtained from birth announcements in the local newspaper. Parents were contacted by letters and follow-up phone calls; they were offered reimbursement for their travel expenses but were not compensated for their participation.

2.1.2. Apparatus

The apparatus consisted of a wooden display box 126 cm high, 102 cm wide, and 36 cm deep, mounted 76 cm above the room floor. The infant faced an opening 43 cm high and 95 cm wide in the front of the apparatus; between trials, a curtain consisting of a muslin-covered frame, 60 cm high and 101 cm wide, was lowered in front of this opening. The side walls of the apparatus were painted white and the floor was covered with gray granite contact paper. The back wall was constructed of gray foam core; at the bottom of the back wall was an opening 5 cm high and 102 cm wide that was filled with gray fringe.

Three wooden screens were used in the experiment. Each screen was 30 cm high, 38 cm wide, 0.5 cm thick, covered with blue contact paper, decorated with green dots, and supported at the back by a metal base. The screen used in the discontinuous-lower-edge display and test trials had an opening extending from its lower edge in its midsection. This opening was 26 cm high, 18 cm wide, and outlined with black tape; above the opening was a strip 4 cm high and 18 cm wide. The screen used in the continuous-lower-edge display and test trials had an identical opening except that it extended from the screen's upper edge.

Two cardboard cylinders were used in the experiment. Each cylinder was 28.5 cm high, 7.5 cm in diameter, and covered with orange contact paper; each cylinder also had five small orange pompons, each 1.5 cm in diameter, attached to its front lower edge. These pompons served two purposes. First, each cylinder was mounted on a hidden carrier 1 cm above the apparatus floor, and the pompoms, which rested on the floor, hid this gap; second, as each cylinder moved across the apparatus, the pompons brushed noiselessly against the floor, giving the infants no auditory information about the cylinder's trajectory behind the screen.

Each cylinder carrier consisted of an "L"-shaped metal rod. The vertical portion of the rod was attached to the back of the cylinder, and the horizontal portion protruded through the opening at the bottom of the apparatus's back wall. Behind the wall, the rod was attached to a felt-covered metal base that rested on a Plexiglas track; an experimenter could move each cylinder smoothly and silently by sliding its base along this track. In the CDNA condition, one cylinder was moved along the left half of the track, and the other cylinder along the right half. In the CA condition, a single cylinder was moved along the entire track. To help the experimenter slide the carriers at an even pace, equally spaced marks were placed above the opening in the back wall of the apparatus. In addition, the experimenter listened to a metronome that beat softly once per second.

The infants were tested in a brightly lit room. Three 20 W fluorescent light bulbs were attached to the front and back walls of the apparatus to provide additional light. Two wooden frames, each 182.5 cm high, 71 cm wide, and covered with blue cloth, stood at an angle on either side of the apparatus; these frames served to isolate the infants from the experimental room.

2.1.3. Events

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

2.1.3.1. CDNA condition. Familiarization event. At the start of the familiarization event, the full screen stood centered on the apparatus floor, 17.5 cm in front of the back wall. One cylinder was visible in the left corner of the apparatus, 2.25 cm from the left wall and 5.5 cm from the back wall; the other cylinder was hidden behind the right edge of the screen. After a 1-s pause, the experimenter slid the left cylinder to the right at a speed of 15 cm/s until it disappeared behind the left edge of the screen (2-s). After a 2-s pause, the experimenter slid the second cylinder to the right until it stood 2.25 cm from the right wall (2-s). After a 1-s pause, the sequence was repeated in reverse. Each event cycle thus lasted about 14 s; cycles were repeated until the computer signaled that the trial had ended (see below). When this occurred, a second experimenter lowered the curtain in front of the apparatus.

Displays. One cylinder stood motionless 7.25 cm from the left edge of the screen with a discontinuous (discontinuous-lower-edge display) or continuous (continuous-lower-edge display) lower edge.

Test events. The test events were identical to the familiarization event, except that the full screen was replaced by the screen with a discontinuous (discontinuous-lower-edge event) or a continuous (continuous-lower-edge event) lower edge.

2.1.3.2. CA condition. The familiarization event, displays, and test events shown in the CA condition were identical to those in the CDNA condition with two exceptions. First, the cylinder was visible in the opening when passing behind the screen in the test events. Second, in the familiarization and test events, only one cylinder was slid across the apparatus, at a constant speed of 15 cm/s. Each familiarization and test event cycle lasted about 14 s, as in the CDNA condition.

2.1.4. Procedure

During the experiment, the infant sat on a parent's lap in front of the apparatus; the infant's head was approximately 55 cm from the screen. Parents were instructed not to interact with their infant during the experiment; they were also asked to close their eyes during the test trials.

The infant's looking behavior was monitored by two observers who watched the infant through peepholes in the cloth-covered frames on either side of the apparatus. The observers could not see the events from their viewpoints and they did not know the order in which the test events were presented. Each observer held a button box linked to a computer and depressed the button when the infant attended to the events. The looking times recorded by the primary observer were used to determine when a trial had ended (see below).

The infants were tested according to a three-phase procedure that consisted of a familiarization, a display, and a test phase. During the *familiarization* phase, the infants saw the familiarization event on six successive trials. These trials served to acquaint the infants with the cylinder and its motion. Each familiarization trial ended when the infant either (1) looked away from the event for 2 consecutive seconds after having looked at it for at least 7 cumulative seconds, or (2) looked for 60 cumulative seconds.

During the *display* phase, the infants saw the discontinuous- and continuous-lower-edge displays on two successive trials. These trials served to familiarize the infants with the test screens, and also gave the infants an opportunity to compare the cylinder to each screen. Each display trial ended when the infant (1) looked away from the display for 2 consecutive seconds after having looked at it for at least 5 cumulative seconds, or (2) looked for 60 cumulative seconds.

During the *test* phase, the infants saw the discontinuous- and continuous-lower-edge test events appropriate for their condition on two successive trials. Half of the infants in each condition saw the screen with a discontinuous lower edge first in the display and test trials, and the other infants saw the screen with a continuous lower edge first.

Each test trial ended when the infant (1) looked away for 1 consecutive second after having looked for at least 15 cumulative seconds, or (2) looked for 60 cumulative seconds. The 15-s minimal value was chosen to give the infants sufficient opportunity to notice that the cylinder failed to appear, or did appear, in the screen opening (recall that each event cycle lasted about 14 s).

To measure the interobserver agreement during the two test trials, each trial was divided into 100-ms intervals, and the computer determined in each interval whether the two observers agreed that the infant was or was not looking at the event. Agreement was calculated for each trial by dividing the number of intervals in which the observers agreed by the total number of intervals in the trial. Interobserver agreement was calculated for all 16 infants and averaged 93% per trial per infant.

Preliminary analyses of the infants' looking times during the test trials revealed no significant interaction among condition, event, and order, $F(1, 8)=1.06$, $P>0.10$, or among condition, event, and sex, $F(1, 8)=1.26$, $P>0.10$; the data were therefore collapsed across order and sex in subsequent analyses.

2.2. Results

2.2.1. Familiarization trials

The infants' looking times during the six familiarization trials (see Fig. 6) were averaged and analyzed by means of a single-factor analysis of variance (ANOVA), with condition (CDNA or CA) as a between-subjects factor. The main effect of condition was not significant, $F(1, 14)=0.47$, indicating that the infants in the two conditions did not differ reliably in their mean looking times during the familiarization trials (CDNA condition: $M=43.4$, $SD=8.4$; CA condition: $M=46.9$, $SD=11.8$).

2.2.2. Display trials

The infants' looking times during the two display trials (see Fig. 6) were analyzed by means of a 2×2 ANOVA with condition (CDNA or CA) as a between-subjects factor and display (discontinuous- or continuous-lower-edge) as a within-subject factor. The main effects of condition, $F(1, 14)=0.30$, and display, $F(1, 14)=0.00$, were not significant. The condition $\times$ display interaction was also not significant, $F(1, 14)=1.53$, $P>0.10$, indicating that the infants in the two conditions did not differ reliably in their looking times during the display trials (CDNA condition: discontinuous-lower-edge display: $M=28.4$, $SD=21.4$; continuous-lower-edge display: $M=22.6$, $SD=16.0$; CA condition: discontinuous-lower-edge display: $M=27.3$, $SD=22.4$; continuous-lower-edge display: $M=33.7$, $SD=22.6$).

2.2.3. Test trials

The infants' looking times during the two test trials (see Fig. 6) were analyzed by means of a 2×2 ANOVA with condition (CDNA or CA) as a between-subjects factor and event (discontinuous- or continuous-lower-edge) as a within-subject factor. The analysis yielded a significant condition $\times$ event interaction, $F(1, 14)=18.94$, $P<0.001$. Planned comparisons revealed that the infants in the CDNA condition looked reliably longer at the discontinuous-lower-edge ($M=47.8$, $SD=12.4$) than at the continuous-lower-edge

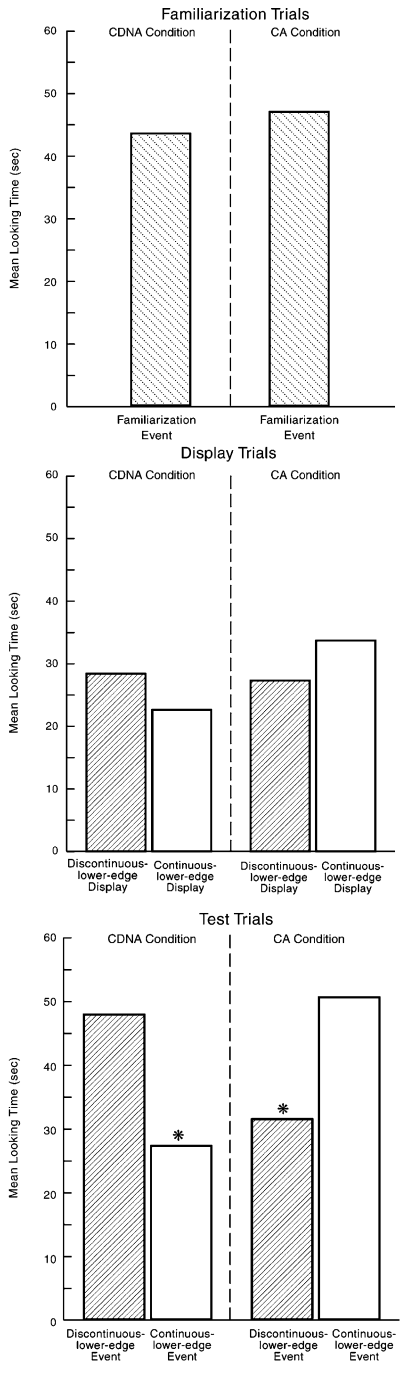

Fig. 6. Mean looking times during the familiarization, display, and test trials of the infants in the CDNA and CA conditions of Experiment 1.

($M = 27.2$, SD $= 14.8$) event, $F(1, 14) = 10.19$, $P < 0.01$, whereas those in the CA condition showed the reverse pattern: they looked reliably longer at the continuous-lower-edge ($M = 50.5$, SD $= 10.4$) than at the discontinuous-lower-edge ($M = 31.4$, SD $= 14.5$) event, $F(1, 14) = 8.77$, $P < 0.025$.[3]

Additional comparisons indicated that the infants (1) looked reliably longer at the discontinuous-lower-edge event when the cylinder failed to appear between the screens than when it did appear, $F(1, 14) = 6.49$, $P < 0.025$, but (2) looked reliably longer at the continuous-lower-edge event when the cylinder appeared between the screens than when it failed to appear, $F(1, 14) = 13.01$, $P < 0.005$.

Inspection of the individual infants' looking times revealed that 14 of the 16 infants ($P < 0.0025$, binomial cumulative probability) looked longer at the event that was unexpected as opposed to expected, given their knowledge of occlusion events (CDNA condition: discontinuous- as opposed to continuous-lower-edge event; CA condition: continuous- as opposed to discontinuous-lower-edge event).

2.3. Discussion

The results of Experiment 1 provide further evidence that 3-month-old infants use the variable lower-edge-discontinuity but not the variable height when reasoning about occlusion events (Aguiar & Baillargeon, 2002; Baillargeon & Devos, 1991). The lower-edge-discontinuity variable enabled the infants in Experiment 1 to respond correctly to the events involving the screen with a *discontinuous* lower edge: the infants viewed the impossible event in which the cylinder failed to appear in the screen's opening as unexpected, and the possible event in which it did appear as expected. However, the lower-edge-discontinuity variable was not sufficient to enable the infants to respond correctly to the events involving the screen with a *continuous* lower edge. Lacking the variable height, the infants expected the cylinder to remain hidden when behind this screen, despite the very large opening extending from its upper edge. Accordingly, the infants erred in two ways: they viewed the impossible event in which the cylinder failed to appear in the screen's opening as expected (an error of omission), and the possible event in which the cylinder did appear as unexpected (an error of commission).

This last result represents the first demonstration of an error of commission in a VOE task. Such a finding strongly suggests that young infants bring to bear variables or rules to

[3] Although the analysis of the display data did not yield a significant condition × display interaction, there was nevertheless a tendency for the infants in the CDNA condition to look longer at the discontinuous- than at the continuous-lower-edge display, and for those in the CA condition to look longer at the continuous- than at the discontinuous-lower-edge display (see Fig. 6). In light of these tendencies, the test data were also subjected to an analysis of covariance (ANCOVA); the factors were the same as in the ANOVA, and the covariates were the infants' mean looking times during the familiarization trials and their looking times during the display trials. The purpose of this analysis was to examine whether the same test results would obtain after adjusting for the differences in the infants' looking times during the familiarization and display trials. The results of the ANCOVA replicated those of the ANOVA: the condition × event interaction was significant, $F(1, 11) = 19.92$, $P < 0.0025$; and planned comparisons confirmed that the infants in the CDNA condition looked reliably longer at the discontinuous- than at the continuous-lower-edge event, $F(1, 11) = 12.25$, $P < 0.005$, whereas those in the CA condition looked reliably longer at the continuous- than at the discontinuous-lower-edge event, $F(1, 11) = 10.71$, $P < 0.01$.

predict the outcomes of physical events. When these rules are still incomplete, infants view as unexpected events that are physically possible and even ordinary, but happen to contradict their faulty rules. Experiment 2 sought further evidence of errors of commission in 2.5-month-old infants' responses to occlusion events.

3. Experiment 2

The 2.5-month-old infants in Experiment 2 were tested using the same procedure as in Experiment 1, with two exceptions. First, the continuous-lower-edge display and test event were replaced with a two-screen display and test event (see Figs. 7 and 8): the short strip below the opening in the screen with a continuous lower edge was removed, leaving two separate screens. Second, we doubled the number of participants and used

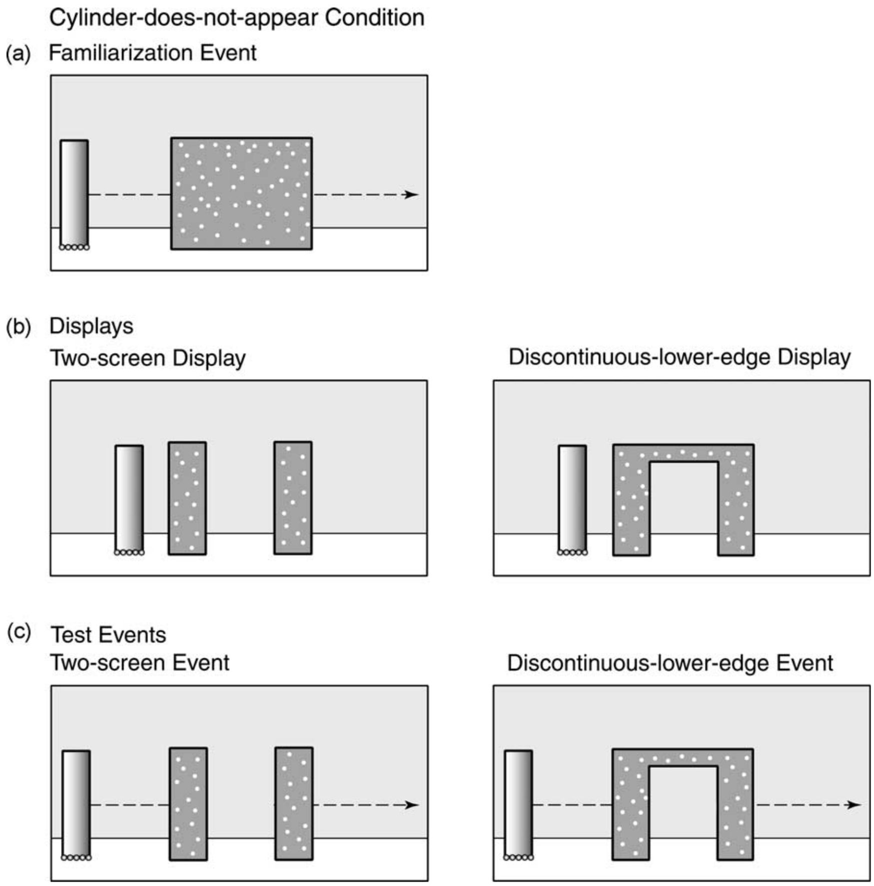

Fig. 7. Schematic drawing of familiarization event, displays, and test events in the cylinder-does-not-appear (CDNA) condition of Experiment 2.

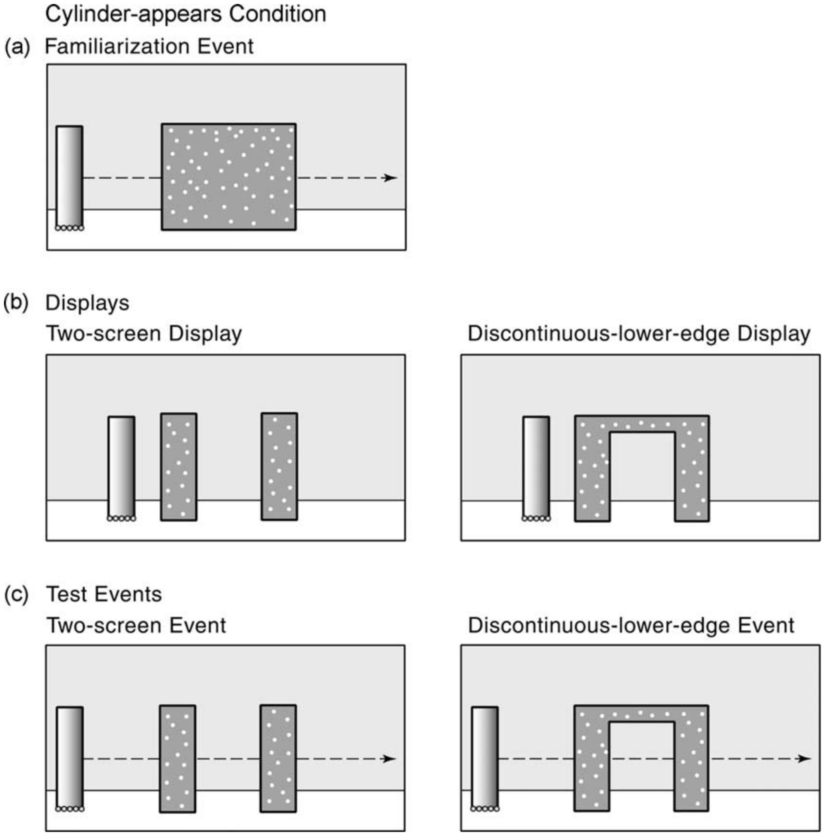

Fig. 8. Schematic drawing of familiarization event, displays, and test events in the cylinder-appears (CA) condition of Experiment 2.

a completely between-subjects rather than a mixed within-subject design: half of the infants in the CDNA and CA conditions saw the discontinuous-lower-edge test event, and half saw the two-screen test event, for a single test trial. Unlike the 3-month-olds in Experiment 1, the 2.5-month-olds in Experiment 2 tended to respond differentially to the test events only on the first test trial they received.[4]

[4] It is not entirely clear why this was the case: after all, Aguiar and Baillargeon (1999) showed their 2.5-month-old infants similar occlusion events and obtained differential responses on two test trials. Several factors could have contributed to this difference. For example, Aguiar and Baillargeon used a toy mouse 14.5 cm tall, whereas we used a cylinder 29 cm tall. The infants in the present experiments might have found the cylinder less engaging, or they might have found it more tiring physically to track such a tall object trial after trial. Recent research suggests that infants' ability to track moving objects improves dramatically in the first three months of life, in part because of the development of head control (e.g. for a review, see Bertenthal & von Hofsten, 1998). In addition, the infants in the experiments of Aguiar and Baillargeon received six to nine habituation trials prior to test, whereas those in the present experiments received six familiarization and two display trials. Perhaps the display trials made the test trials less interesting: because the infants had already seen the test screens, they became bored more rapidly.

As in Experiment 1, the infants in the CDNA condition were shown two *impossible* test events. Because at 2.5 months infants have identified the variable behind/not-behind but not the variable lower-edge-discontinuity as relevant to occlusion events, we predicted that the infants should view only one of these events as unexpected. Specifically, they should view the event in which the cylinder failed to appear between the two screens as unexpected (a correct response), but they should view the event in which the cylinder failed to appear behind the screen with a discontinuous lower edge as expected (an error of omission). The infants shown the two-screen event should thus look reliably longer than those shown the discontinuous-lower-edge event.

Again as in Experiment 1, the infants in the CA condition were shown two *possible* test events. Because 2.5-month-old infants have identified behind/not-behind but not lower-edge-discontinuity as an occlusion variable, we predicted that the infants should view only one of these events as expected. Specifically, the infants should view the event in which the cylinder appeared between the two screens as expected (a correct response), but they should view the event in which the cylinder appeared behind the screen with a discontinuous lower edge as unexpected (an error of commission). The infants shown the discontinuous-lower-edge event should thus look reliably longer than those shown the two-screen event. As in Experiment 1, opposite patterns of looking were thus predicted for the CDNA and CA conditions.

3.1. Method

3.1.1. Participants

Participants were 32 healthy term infants, 16 male and 16 female (range $=79$ to 90 days, $M=84.7$ days). Another 24 infants were tested but eliminated, because of fussiness (13), drowsiness (6), inattentiveness (3), procedural problems (1), or parental interference (1). Eight infants, 4 male and 4 female, were assigned to each of the four experimental groups formed by crossing the two cylinder (CDNA or CA) and the two screen (two-screen or discontinuous-lower-edge) conditions.

3.1.2. Apparatus and events

The apparatus and events used in Experiment 2 were similar to those in Experiment 1 with one exception: the continuous-lower-edge display and test event were replaced by a two-screen display and test event. The two screens were identical to and were placed in the same positions as those in the continuous-lower-edge display and test event, without the short strip at the bottom to connect them.

3.1.3. Procedure

The procedure used in Experiment 2 was similar to that in Experiment 1 except that the infants received only one test trial in which they saw the event appropriate for their cylinder and screen condition. Interobserver agreement during the test trial was calculated for 30 of the 32 infants (only one observer was present for two infants), and averaged 96% per infant. Preliminary analyses of the test data revealed that the interaction among cylinder condition, screen condition, and sex was not significant,

$F(1, 24)=1.18$, $P>0.10$; the data were therefore collapsed across sex in subsequent analyses.

3.2. Results

3.2.1. Familiarization trials

The infants' looking times during the six familiarization trials (see Fig. 9) were averaged and analyzed by means of a 2×2 ANOVA with cylinder condition (CDNA or CA) and screen condition (two-screen or discontinuous-lower-edge) as between-subjects factors. The main effects of cylinder condition, $F(1, 28)=0.00$, and screen condition, $F(1, 28)=0.14$, were not significant. The cylinder condition×screen condition interaction was also not significant, $F(1, 28)=0.28$, indicating that the infants in the four different conditions did not differ reliably in their mean looking times during the familiarization trials (CDNA two-screen condition: $M=39.3$, SD=14.2; CDNA discontinuous-lower-edge condition: $M=38.6$, SD=12.2; CA two-screen condition: $M=37.1$, SD=11.8; CA discontinuous-lower-edge condition: $M=41.1$, SD=12.2).

3.2.2. Display trials

The infants' looking times during the two display trials (see Fig. 9) were analyzed by means of a 2×2×2 ANOVA with cylinder condition (CDNA or CA) and screen condition (two-screen or discontinuous-lower-edge) as between-subjects factors and display (two-screen or discontinuous-lower-edge) as a within-subject factor. The main effects of cylinder condition, $F(1, 28)=0.60$, screen condition, $F(1, 28)=1.39$, $P>0.10$, and display, $F(1,28)=0.57$, were not significant. In addition, the cylinder condition×screen condition×display interaction was not significant, $F(1, 28)=2.35$, $P>0.10$, indicating that the infants in the four conditions did not differ reliably in their looking times during the two display trials (CDNA two-screen condition: two-screen display: $M=32.9$, SD=20.0; discontinuous-lower-edge display: $M=45.8$, SD=19.3; CDNA discontinuous-lower-edge condition: two-screen display: $M=31.1$, SD=25.0; discontinuous-lower-edge display: $M=23.6$, SD=18.3; CA two-screen condition: two-screen display: $M=35.0$, SD=16.0; discontinuous-lower-edge display: $M=24.7$, SD=22.9; CA discontinuous-lower-edge condition: two-screen display: $M=30.8$, SD=22.1; discontinuous-lower-edge display: $M=24.0$, SD=19.5).

3.2.3. Test trial

The infants' looking times during the test trial (see Fig. 9) were analyzed by means of a 2×2 ANOVA with cylinder condition (CDNA or CA) and screen condition (two-screen or discontinuous-lower-edge) as between-subjects factors. The analysis yielded a significant cylinder condition×screen condition interaction, $F(1, 28)=17.22$, $P<0.0005$. Planned comparisons revealed that in the CDNA condition the infants who saw the two-screen event ($M=54.7$, SD=9.7) looked reliably longer than those who saw the discontinuous-lower-edge event ($M=33.5$, SD=18.7), $F(1, 28)=8.82$, $P<0.01$, whereas in the CA condition the reverse pattern was found: the infants who saw

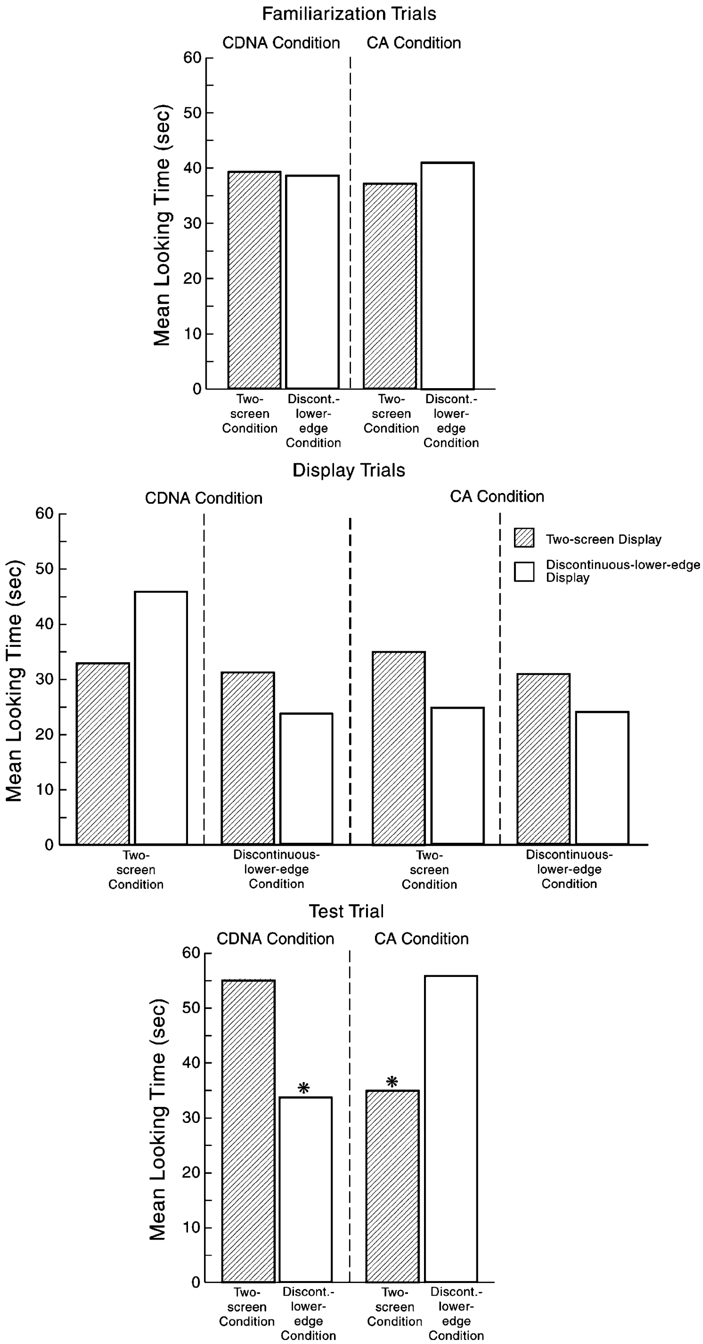

Fig. 9. Mean looking times during the familiarization, display, and test trials of the infants in the two cylinder and the two screen conditions of Experiment 2.

the discontinuous-lower-edge event ($M = 55.5$, $SD = 12.8$) looked reliably longer than those who saw the two-screen event ($M = 34.8$, $SD = 14.3$), $F(1, 28) = 8.40$, $P < 0.01$.[5]

Additional comparisons indicated that the infants (1) looked reliably longer at the two-screen event when the cylinder failed to appear between the screens than when it did appear, $F(1, 28) = 7.81$, $P < 0.01$, but (2) looked reliably longer at the discontinuous-lower-edge event when the cylinder appeared in the screen's opening than when it failed to appear, $F(1, 28) = 9.44$, $P < 0.005$.

Inspection of the individual infants' looking times revealed that many of the infants who saw a test event that was unexpected, given their knowledge of occlusion, looked for the maximum allowed (60 s): 6 of the 8 infants who saw the CDNA two-screen event and 7 of the 8 infants who saw the CA discontinuous-lower-edge event did so. In contrast, few of the infants who saw a test event that was expected, given their knowledge of occlusion, looked for 60 s: only 2 of the 8 infants who saw the CDNA discontinuous-lower-edge event and 1 of the 8 infants who saw the CA two-screen event did so. A chi-square test comparing the numbers of infants who looked for 60 s at the unexpected (13/16) and expected (3/16) events yielded a reliable difference, $\chi^2_1 = 12.5$, $P < 0.0005$.

3.3. Discussion

The results of Experiment 2 provide further evidence that 2.5-month-old infants use the variable behind/not-behind but not the variable lower-edge-discontinuity when reasoning about occlusion events (Aguiar & Baillargeon, 2002). The behind/not-behind variable enabled the infants in Experiment 2 to respond correctly to the events involving the *two separate screens*: they viewed the impossible event in which the cylinder failed to appear between the screens as unexpected, and the possible event in which the cylinder did appear as expected. However, the behind/not-behind variable was not sufficient to enable the infants to respond correctly to the events involving the *screen with a discontinuous lower edge*. Lacking the variable lower-edge-discontinuity, the infants expected the cylinder to remain hidden when behind this screen. Accordingly, the infants erred in two ways: they viewed the impossible event in which the cylinder failed to appear in the screen's opening as expected (an error of omission), and the possible event in which the cylinder did appear as unexpected (an error of commission).

This last result indicates that infants as young as 2.5 months of age produce errors of commission in their responses to occlusion events. This finding again provides strong evidence that young infants bring to bear variables or rules when reasoning about physical events, and view events that violate their rules–even ordinary, possible events–as unexpected.

[5] An ANCOVA examining the test data of Experiment 2, using the infants' mean looking times during the familiarization trials and their looking times during the display trials as covariates, replicated the results of the ANOVA. The cylinder condition × screen condition interaction was significant, $F(1, 25) = 12.52$, $P < 0.0025$; and planned comparisons confirmed that in the CDNA condition the infants who saw the two-screen event looked reliably longer than those who saw the discontinuous-lower-edge event, $F(1, 25) = 5.34$, $P < 0.05$, whereas in the CA condition the infants who saw the discontinuous-lower-edge event looked reliably longer than those who saw the two-screen event, $F(1, 25) = 8.83$, $P < 0.01$.

4. Transient preferences?

The infants in the CDNA conditions of Experiments 1 and 2 were presented with two impossible test events, and those in the CA conditions with two possible test events. The infants in each condition viewed one event as unexpected and one event as expected. We suggested that their limited knowledge of occlusion (1) led the infants in the CDNA conditions to view one of the impossible events they were shown as expected (an error of omission) and (2) led the infants in the CA conditions to view one of the possible events they were shown as unexpected (an error of commission).

But could another interpretation be offered for the results of Experiments 1 and 2? A number of researchers have argued that young infants may respond with increased attention to some events in VOE tasks, not because these events violate their physical knowledge, but because the habituation or familiarization trials induce in them transient and superficial preferences for the events (e.g. Bogartz, Shinskey, & Schilling, 2000; Bogartz et al., 1997; Cashon & Cohen, 2000; Cohen & Marks, 2002; Schilling, 2000). We refer to such accounts as *transient-preference* accounts (for a detailed discussion and test of such accounts, see Wang et al., 2004).

One transient-preference account, put forth by Bogartz et al. (1997), is particularly germane to the research discussed in this article. This account addressed the results of Baillargeon and Devos (1991), described in the Introduction (see also Baillargeon & Graber, 1987; Luo, Baillargeon & Lécuyer, 2005). Recall that in this experiment 3.5-month-old infants were familiarized with a tall or a short toy carrot 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 (impossible event) and the short (possible event) carrot slide back and forth behind the screen; neither carrot appeared in the window (see Fig. 2(a)). The infants looked reliably longer at the impossible than at the possible event, and Baillargeon and DeVos took this result to suggest that the infants expected the tall but not the short carrot to appear in the window. The account proposed by Bogartz et al. was very different: they suggested that the infants focused on the carrot'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 presence of the window in the impossible but not the possible event. The infants thus responded to the impossible event with increased attention simply because they noticed the screen change in this event.

This account could also be used to explain the other positive occlusion findings discussed in the Introduction. Perhaps the 3- and 2.5-month-old infants tested by Aguiar and Baillargeon (1999, 2002) looked reliably longer when the toy mouse failed to appear in the screen's low window (see Fig. 2(b)) or between the two screens (see Fig. 2(c)), simply because they focused on the mouse's face during the habituation trials, scanned only the portion of the screen at the same height as the face, and hence detected the screen change in the impossible but not the possible test event.

However, several results, including those of the present research, suggest that this transient-preference account is unlikely. First, the account cannot explain the fact that the 3-month-old infants tested by Baillargeon and Devos (1991) did not respond with increased attention when the tall carrot failed to appear in the screen's high window (see Fig. 2(a)), or that the 2.5-month-old infants tested by Aguiar and Baillargeon (1999) did not respond with increased attention when the mouse failed to appear in the screen's low window (see Fig. 2(b)). Second, the account cannot explain why each of the positive results illustrated in Fig. 2 was eliminated in control experiments in which the infants were shown that two carrots or two mice were present in the apparatus (Aguiar & Baillargeon, 1999, 2002; Baillargeon & Devos, 1991); the infants were apparently able to take advantage of this "hint" to produce an explanation for the impossible events (see also Aguiar & Baillargeon, 2002, for evidence that in some conditions 3.5-month-old infants spontaneously generated two-mouse explanations).

Third, the present results provide further evidence against the transient-preference account of Bogartz et al. (1997). This account predicts that the 3-month-old infants in Experiment 1, who were tested with a *faceless* cylinder, should be about as likely to detect the screen change in the discontinuous- or the continuous-lower-edge test event, and so should tend to look equally at the two events. Similarly, the 2.5-month-old infants in Experiment 2, who were tested with the same faceless cylinder, should be about as likely to detect the screen change in the two-screen or the discontinuous-lower-edge test event, and so should tend to look equally at the two events. However, neither of these predictions was confirmed: the results of Experiments 1 and 2 replicated those of Aguiar and Baillargeon (1999, 2002), even though the object was a faceless cylinder.

It might be objected that, when a faceless object is used, infants tend to focus on the top or bottom of the object, so that a transient-preference account is still possible. To illustrate, consider the results of Experiment 1. One might suggest that the infants in the CDNA condition focused on the *bottom* of the cylinder, scanned only the bottom of the screen, and hence detected the screen change in the discontinuous- but not the continuous-lower-edge test event. There are several difficulties with this account. First, in order to explain the results of the CA condition, one would need to assume that the infants focused on a different portion of the cylinder–even though they received identical familiarization trials. Specifically, one would need to assume that the infants focused on the *top* of the cylinder, scanned only the top of the screen, and hence detected the screen change in the continuous- but not the discontinuous-lower-edge test event. Another difficulty is that, if the infants in Experiment 1 merely responded to the screen change following the familiarization trials, then similar results would be expected in the display trials. However, as noted earlier, the infants in Experiment 1 looked about equally at the discontinuous- ($M=27.9$, $SD=21.2$) and continuous-lower-edge ($M=28.2$, $SD=19.8$) displays, $F(1, 14)=0.00$. Finally, this alternative account rests on the notion that infants may process only a narrow portion of the stimuli before them (Bogartz et al., 1997); such a notion becomes less tenable when infants are shown, as in the present research, very salient violations. For example, to argue that the infants in the CDNA condition of Experiment 1 failed to detect the screen change in the continuous-lower-edge event, one must be willing to admit that the infants attended to the 4-cm strip at the bottom of the screen–and failed to notice the 26-cm opening above it.

5. General discussion

The present research provides the first experimental demonstration that young infants' incomplete physical knowledge leads them to produce not only errors of omission but also errors of commission in VOE tasks. In Experiment 1, 3-month-old infants' limited knowledge of occlusion events led them to view as unexpected a possible event in which a tall cylinder became visible when passing behind a tall screen with a very large opening extending from its upper edge. In Experiment 2, 2.5-month-old infants' limited knowledge of occlusion events similarly led them to view as unexpected a possible event in which a tall cylinder became visible when passing behind a tall screen with a very large opening extending from its lower edge.

The errors of commission observed in the present research are important for several reasons. First, they confirm the developmental sequence proposed by Aguiar and Baillargeon (1999, 2002), based on the errors of omission they observed in infants' responses to occlusion events. This does not mean, of course, that this sequence is not in need of further specification. In order to correctly characterize young infants' knowledge of when objects behind occluders should and should not be hidden, much additional research will be needed. For example, in all of the experiments discussed in this article, the object and occluder stood on the same horizontal plane; how would infants respond if they did not? Furthermore, what if infants were shown occluders with internal openings rather than occluders with openings extending from their upper or lower edges, as in the present research? The answers to these and related questions will no doubt bring about elaborations of the developmental sequence identified by Aguiar and Baillargeon (1999, 2002) and supported by the present research.

Second, infants' errors of commission provide a new kind of evidence for the incremental-knowledge account described in introduction. If infants form event categories, identify vectors within each category, and for each vector identify a sequence of variables that enables them to predict outcomes more and more accurately, then it should be the case that when this sequence is still incomplete, infants view as unexpected ordinary, commonplace events that happen to contradict their faulty knowledge.

Third, infants' errors of commission argue against comparison accounts which claim that infants in VOE tasks simply detect mismatches between odd, impossible events and similar remembered events (e.g. Bogartz et al., 1997; Haith, 1998, 1999; Thelen & Smith, 1994). Such accounts cannot easily explain why infants would detect mismatches between ordinary, possible events and similar remembered events. A notion of rule appears to be essential for theorizing about cognitive development, even in early infancy.

In the following sections, we first review additional evidence that infants produce errors of commission when their physical knowledge is still incomplete. Next, we discuss evidence that errors of commission provide a powerful tool for diagnosing the vectors underlying infants' responses to events.

5.1. Errors of commission in other event categories

The incremental-knowledge account presented in the Introduction predicts that errors of commission should be obtained in older as well as in younger infants. Two experiments in our laboratory investigated errors of commission in older infants.

One experiment focused on 7.5-month-old infants' knowledge of support events (Wang, 2003). By this age, infants have already identified the variable amount of contact: they expect an object to fall when less than half of its bottom surface is supported (e.g. Baillargeon et al., 1992). However, infants do not yet realize that an object can be stable with less than half of its bottom surface supported, when it is the *middle* portion of the object that is supported; this variable, balance, is typically not identified until about 8.5 months of age (e.g. Dan et al., 2000; Huettel & Needham, 2000; Wang & Baillargeon, 2005). The infants saw two test events in which an experimenter's gloved hand placed a box on a platform 10 cm wide; in each case, the middle portion of the box rested on the platform. In one event, the box was 30 cm wide, so that only the middle 33% of its bottom surface was supported (wide-box event); in the other event, the box was 15 cm wide so that the middle 66% of its bottom surface was supported (narrow-box event). The two boxes were identical except for their width. The infants looked reliably longer at the wide- than at the narrow-box event. This and control results suggested that the infants still lacked the variable balance: they expected the wide box to fall, because less than half of its bottom surface was supported. The infants' limited knowledge of support thus led them to produce an error of commission: they perceived an ordinary, possible event in which a wide box remained balanced on a narrow support as unexpected.

The other experiment focused on 7-month-old infants' knowledge of occlusion events (Luo & Baillargeon, 2005a). At this age, infants do not yet realize that an object should be visible when placed behind a transparent occluder; this variable, transparency, is typically not identified until about 7.5 months of age (Luo & Baillargeon, 2005a). The infants saw two test events. At the start of each event, an object stood next to an occluder taller and wider than the object; the occluder was made of transparent Plexiglas and its edges were outlined with red tape. To start, a screen was raised to hide the occluder, and an experimenter's gloved hand lifted the object and lowered it behind the hidden transparent occluder. Next, the screen was lowered to reveal the occluder with either the object standing behind it (object-present event), or no object behind it (object-absent event). The infants looked reliably longer at the object-present than at the object-absent event. This and control results suggested that the infants still lacked the variable transparency. The occluder was taller and wider than the object, and presented no openings, so the infants expected the object to be hidden when behind the occluder. The infants thus produced an error of commission: their limited knowledge of occlusion led them to view an ordinary, possible event—an object that remained visible when placed behind a transparent occluder—as unexpected.

5.2. A diagnostic tool for infants' vectors

Beyond providing additional evidence that infants' physical reasoning is rule-based, errors of commission may serve as a useful tool for determining *which* vectors or problems infants have identified in an event category.

To see why, consider first two errors of commission in infants' responses to *occlusion* events. In the present research, 3- and 2.5-month-old infants saw a tall cylinder move back and forth behind a tall screen with a discontinuous lower edge; the cylinder either appeared or did not appear when passing behind the screen. The 3-month-old infants looked reliably longer when the cylinder did not appear than when it did appear (a correct response), whereas the 2.5-month-old infants showed the reverse looking pattern (an error of *commission*). In the research mentioned in the last section (Luo & Baillargeon, 2005a), 7.5- and 7-month-old infants saw an object being lowered behind a transparent occluder; the object was either visible or not visible through the front of the occluder. The 7.5-month-old infants looked reliably longer when the object was not visible than when it was visible (a correct response), but the 7-month-old infants showed the reverse response (an error of *commission*). In each case, the infants' error of commission provided evidence that (1) they had formed a vector having to do with whether objects behind occluders should be hidden or visible, and (2) they still lacked some of the variables in the vector and hence made some false predictions: for example, they mistakenly expected an object to be hidden when behind a screen with a discontinuous lower edge (2.5 months), or when behind a transparent screen (7 months).

Contrast these results with those of recent experiments on *containment* events (Luo & Baillargeon, 2005b). In one experiment, for example, 9.5- and 8.5-month-old infants saw an object being lowered inside a transparent container; the object was either visible or not visible through the container. The 9.5-month-old infants looked reliably longer when the object was not visible than when it was visible (a correct response), but the 8.5-month-old infants tended to look equally at the two events (an error of *omission*). The fact that the younger infants produced an error of omission, rather than one of commission, suggested that they had *not* yet identified a vector having to do with whether objects inside containers should be hidden or visible. The infants apparently had no basis—no vector or variable—for predicting whether the object should be hidden or visible when inside the transparent container.

This conclusion has implications for the results of recent experiments on infants' ability to consider height information in containment events. These experiments indicate that infants aged 7.5 months and older look reliably longer when a tall object becomes fully hidden inside a short as opposed to a tall container (e.g. Hespos & Baillargeon, 2001a; Wang et al., in press). This and control results make clear that infants have identified the variable height as relevant to containment events, but to which vector does this variable belong? This vector is unlikely to involve predicting whether objects inside containers should be hidden or visible; as we just saw, even 8.5-month-old infants still lack such a vector (Luo & Baillargeon, 2005b). A more likely possibility, given all of these results, is that the variable height is added to a vector having to do with whether objects placed inside containers should protrude *above* the containers. In other words, infants at this age would be concerned simply with the question of whether an object placed inside a container should be visible above it. In the experiments of Luo and Baillargeon, the object lowered inside the transparent container was shorter than the container. The 8.5-month-old infants could thus use their knowledge of the variable height to predict that no portion of the object would be visible *above* the container. However, the infants could make no prediction as to whether the portion of the object *inside* the container should be hidden or visible. Apparently, it is not until infants are about 9.5 months of age that they form a vector having to do with whether objects inside containers should be hidden or visible (Luo & Baillargeon, 2005b).

The preceding speculations lead to several striking predictions concerning 8.5-month-old infants' responses to events involving transparent containers. For example, they suggest that, when shown an event in which a tall object is lowered inside a short transparent container, infants should look reliably longer if the top of the object is not visible, as opposed to visible, above the container. However, as long as the top of the object protrudes above the container, infants should look about equally whether the bottom of the object is visible, or not visible, through the container. Experiments are under way to test these predictions.

The preceding discussion thus makes clear how the presence or absence of errors of commission may be helpful in specifying which vectors infants have identified in an event category. When infants are shown events with contrastive outcomes (e.g. an object either is or is not visible), an error of commission signals the presence of a vector relevant to these outcomes; an error of omission, in contrast, signals the absence of such a vector.

5.3. Concluding remarks

The incremental-knowledge account predicts that infants who have not yet identified a variable in a vector of an event category (1) should view impossible events consistent with their faulty knowledge as expected, and (2) should view possible events–even ordinary, commonplace events–inconsistent with their faulty knowledge as unexpected. The present results confirmed both of these predictions.

The present research thus demonstrates that whether infants perceive impossible events as unexpected, and possible events as expected, crucially depends on their physical knowledge. In infants as in older children and adults, what is unexpected or expected clearly lies in the mind of the beholder (e.g. Caramazza, McCloskey, & Green, 1981; Carey, 1985; Karmiloff-Smith & Inhelder, 1975; Keil, 1991; McCloskey, 1983; Proffitt, Kaiser, & Whelan, 1990; Siegler, 1978; Vosniadou & Brewer, 1992).

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