Research Article

Inducing Infants to Detect a Physical Violation in a Single Trial

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ABSTRACT—*There is increasing evidence that infants' representations of physical events can be enhanced through appropriate experiences in the laboratory. Most of this research has involved administering infants multiple training trials, often with multiple objects. In the present research, 8-month-olds were induced to detect a physical violation in a single trial. The experiments built on previous evidence that for occlusion events, infants encode height information at about age 3.5 months, but for covering events, they encode height information only at about age 12 months. In two experiments, a short cover was first placed in front of a short or a tall object (occlusion event); next, the cover was lowered over the tall object until it became fully hidden (covering event). Exposure to the occlusion event (but not other events in which height information was not encoded) enabled the infants to detect the violation in the covering event, much earlier than they would have otherwise.*

As adults, we possess a great deal of knowledge about how objects move and interact. This knowledge helps us encode key information about events, and therefore better predict their outcomes. For example, because we know that the height of an object relative to that of a rigid cover determines whether the object will become fully or partly hidden under the cover, we typically encode information about the heights of objects and covers when watching covering events. Thus, if shown an event in which a tall object becomes fully hidden under a short cover, we readily detect the violation.

Because infants' physical knowledge is limited, they do not always encode key information about events. For example, by 8 months of age, infants respond with increased attention in violation-of-expectation tasks when a tall object becomes fully hidden behind a short screen or inside a short container (e.g., Baillargeon & Graber, 1987; Hespos & Baillargeon, 2001), but not when a tall object becomes fully hidden under a short cover or inside a short tube (e.g., Wang, Baillargeon, & Paterson, 2005). These negative findings cannot stem from a general inability to reason about covers and tubes, because even young infants possess expectations about covering and tube events (e.g., Baillargeon, 1995; Wang et al., 2005). Rather, these findings reflect 8-month-old infants' failure to encode height information when representing covering and tube events.

A recent account of infants' physical reasoning helps explain this point (e.g., Baillargeon, 2002; Wang et al., 2005). According to this account, when watching a physical event, infants build a specialized representation of the event that is used to predict and interpret its outcome. To start, infants represent the basic spatial and temporal information about the event and use this information to categorize the event (e.g., Casasola, Cohen, & Chiarello, 2003; McDonough, Choi, & Mandler, 2003). Infants then access their knowledge of the category selected; this knowledge specifies the variables (e.g., height, width, or color) that have been identified as relevant for predicting outcomes in the category,[1] and hence that should be included in the representation (e.g., Wang, Baillargeon, & Brueckner, 2004; Wilcox, 1999). Both the basic and the variable information included in the representation become subject to a few core constraints, including that of continuity (e.g., Baillargeon, Li, Luo, & Wang, in press; Spelke, 1994).[2]

According to the preceding account, 8-month-olds fail to detect height violations in covering and tube events because (a) they

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[1]One of the main factors that determine at what age a variable is identified in an event category is exposure to appropriate observations for the variable (e.g., Baillargeon, 2002; Wang & Baillargeon, 2005).

[2]We define the continuity constraint as follows: Objects exist and move continuously in time and space, retaining their physical properties as they do so (Baillargeon et al., in press).

have not yet identified the variable height as relevant to these event categories, and hence (b) they typically do not include height information when representing events from these categories.

THE PRESENT RESEARCH

The reasoning account just presented predicts that if infants could be induced to include information about a variable they have not yet identified as relevant to an event category when representing events from that category, they might detect violations involving the variable much earlier than they would otherwise.

There already is evidence consistent with this prediction: A few investigations have shown that infants who are primed or taught to encode information about a variable they have not yet identified for an event category succeed in detecting violations involving that variable (e.g., Baillargeon, 1998; Wang & Baillargeon, 2005; Wilcox & Chapa, 2004). These experiments have involved multiple trials with multiple objects. For example, Wilcox and Chapa (2004) primed 7.5-month-olds to include color information in their representations of occlusion events;[3] color is typically not identified as an occlusion variable until about 11.5 months of age (Wilcox, 1999). The infants received six priming trials in which an experimenter used a green cup to pound a peg and a red cup to pour salt; different green and red cups were used across trials. Following these trials, the infants detected a violation when a green ball and a red ball emerged successively from behind a screen too narrow to hide them both. This priming effect was eliminated when the infants received only four training trials, or when the same cups were used across trials.

The present research used a very different approach to induce infants to include information about a variable in their representations of events. The point of departure for this approach was the following question: What would happen if infants were exposed to two events involving the same objects, first an event in a category for which a variable *had* been identified, and then an event in a category for which this same variable had *not* yet been identified? According to the reasoning account, the infants would encode information about the variable in their representation of the first event; if this information remained available, or was again encoded, when the infants represented the second event, then the infants would be able to detect a violation involving the variable in the second event. Thus, a single exposure to a single event—as long as it was the right event—would enable infants to detect a violation. The present research tested this prediction, in experiments focusing on 8-month-olds' use of the variable height in covering events.

[3]In an occlusion event, an object moves or is placed behind a nearer object, or occluder.

EXPERIMENT 1

Although the variable height is not identified in covering events until infants are about 12 months old (e.g., McCall, 2001; Wang et al., 2005), it is identified much earlier, at about age 3.5 months, in occlusion events (e.g., Baillargeon & DeVos, 1991). Experiment 1 took advantage of this décalage to induce 8-month-olds to include height information in their representations of covering events. We reasoned that if, prior to seeing a cover being lowered over an object, infants saw the same cover being placed in front of the object, then (a) they would include information about the heights of the cover and object in their representation of the occlusion event, and (b) this height information might still be available, or might again be encoded, when the infants next represented the covering event.

Half of the infants in Experiment 1 received a single test trial in which they saw an occlusion and then a covering event (occlusion-covering condition; see Fig. 1). At the start of the trial, a cover and a tall object stood side by side. An experimenter's hand rested on the apparatus floor and maintained this position until the infant had looked at the scene for 2 cumulative seconds; this pause allowed the infant to inspect the stimuli and to compare their heights. Following the pause, the hand slid the cover in an arc in front of the object and then slid it back to its initial position. Next, the hand lifted the cover and lowered it over the object until it became fully hidden; the hand then released the cover and paused on the apparatus floor until the trial ended. For half of the infants, the cover used in the occlusion and covering events was slightly taller than the object (tall-cover trial); for the other infants, the cover was only about half as tall, so that it should have been impossible for the object to become fully hidden under the cover (short-cover trial). We reasoned that if the infants included height information in their representations of the occlusion and covering events, then they would be able to detect the height violation in the short-cover trial. The infants who received the short-cover trial were thus expected to look reliably longer than those who received the tall-cover trial.

Infants in another condition received a similar short- or tall-cover test trial, except that the occlusion event was replaced with a display event in which the hand slid the cover forward next to the object, without hiding any portion of it (display-covering condition; see Fig. 1).[4] Because there was no particular reason for the infants to include information about the heights of the cover and object in their representation of the display event, we anticipated that no height information would be available when the infants next represented the covering event. Looking times of the infants who received the short- and tall-cover trials were thus expected to be about equal.

[4]We use the term display event for ease of description. It is unclear whether infants interpret an event in which a hand slides an object solely in terms of its basic information, or in terms of some event category.

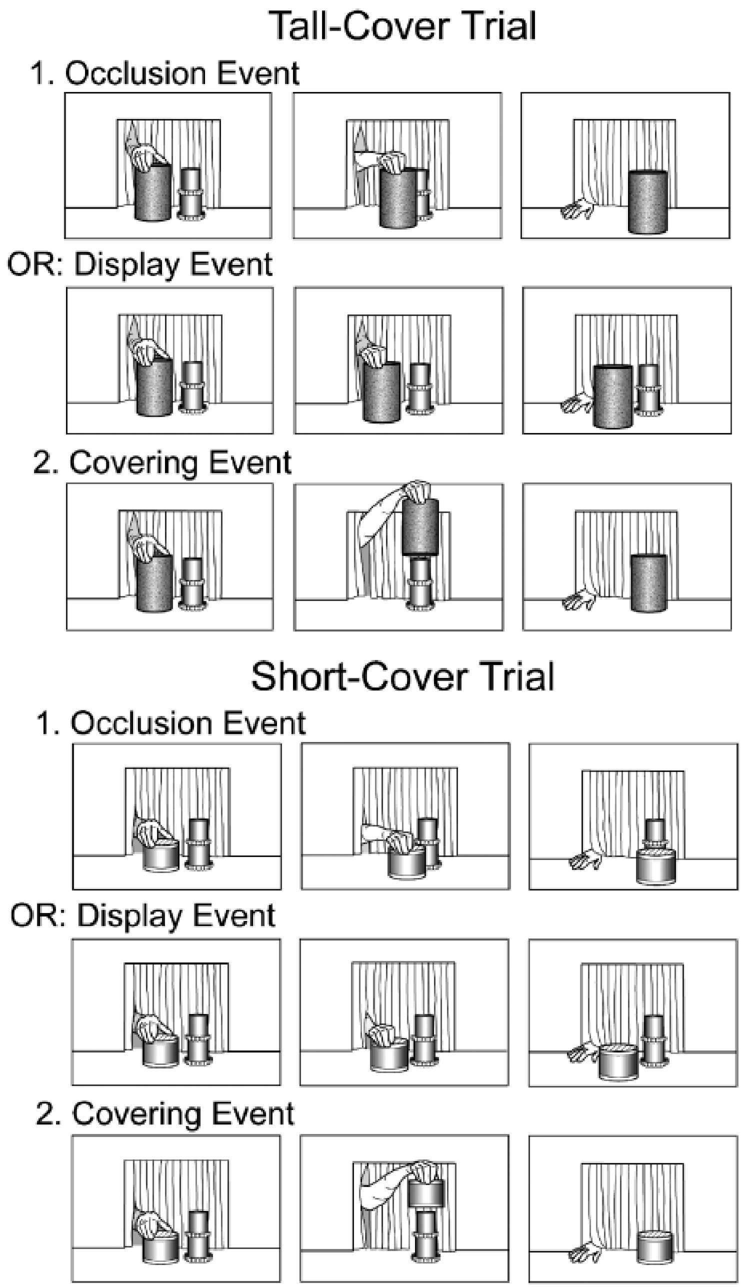

Fig. 1. Test trials in the occlusion-covering and display-covering conditions of Experiment 1. The infants first saw an occlusion or a display event and then a covering event; the cover was either tall (top panel) or short (bottom panel). To start, the hand grasped the cover (1 s) and slid it either in front of or next to the object (2 s); the hand then withdrew to its initial position on the apparatus floor (2 s). When the infants had looked at the scene for 5 cumulative seconds, the hand again grasped the cover (1 s), and returned it to its starting position (2 s). After a 1-s pause, the hand lifted the cover (1 s), moved it to the right (1 s), and lowered it over the object until it became fully hidden (2 s). Finally, the hand returned to its initial position (1 s). The infants watched this final paused scene until the trial ended.

Method

Participants

Participants were 36 healthy term infants, 18 male and 18 female (M = 8 months 5 days; range = 7 months 24 days to 8 months 26 days). Another 2 infants were eliminated because they were distracted. Half of the infants were assigned to the occlusion-covering condition, and half to the display-covering condition; within each condition, half of the infants received a short-cover trial and half a tall-cover trial.

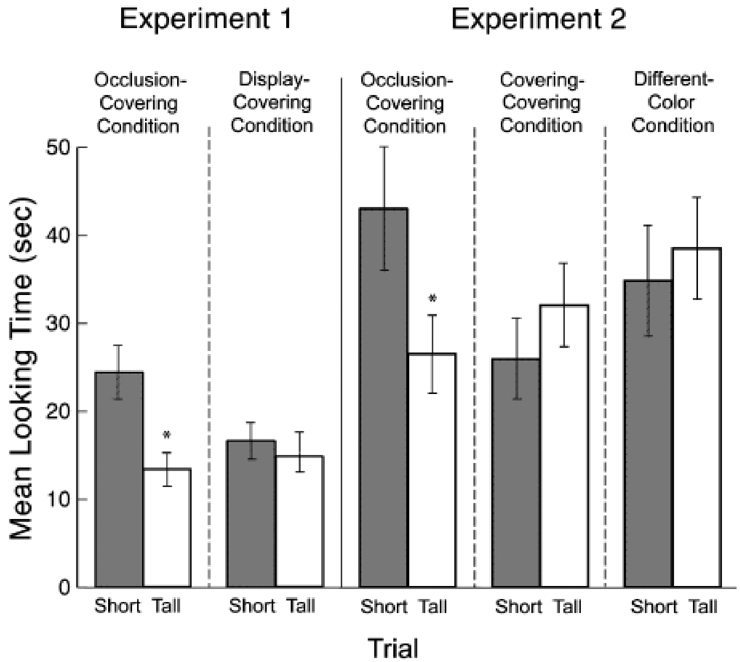

Fig. 2. Mean looking times of the infants in the occlusion-covering and display-covering conditions of Experiment 1 and in the occlusion-covering, covering-covering, and different-color conditions of Experiment 2, during the main-trial portion of the short- and tall-cover test trials. Error bars represent standard errors.

Apparatus

The apparatus consisted of a wooden display box (106 cm high × 101 cm wide × 35 cm deep) that was mounted 76 cm above the room floor. The floor and back wall of the apparatus were covered with pastel paper, and the side walls were painted white. Each infant sat on a parent's lap and faced an opening (41 × 95 cm) in the front of the apparatus; the opening was hidden by a curtain that was raised at the start of the trial. An experimenter introduced his or her right hand (in a yellow rubber glove) into the apparatus through a curtained window (36 × 43 cm) in the back wall.

The covers were 11.5 cm in diameter and made of plastic piping material. The tall cover was colored like gray granite and 17 cm tall; the short cover was green, 8.5 cm tall, and decorated at the top and bottom with yellow stripes. The object was red, collapsible, made of cardboard, and composed of two distinct parts. The upper part was 6 cm in diameter and 7 cm tall; the lower part was 6.5 cm in diameter, 8 cm tall, and decorated at the top and bottom with orange pom-poms. Prior to the test sessions, the experimenter showed the infants the two covers and a noncollapsible replica of the object.

Procedure

Each infant received a short- or a tall-cover test trial. In either case, the infant saw an occlusion or a display event followed by a covering event (pretrial) and then watched the same paused scene until the trial ended (main trial). Looking times during the pretrial and main trial were computed separately. The main trial ended when the infant (a) looked away from the paused scene for 2 consecutive seconds after having looked at it for at least 4 cumulative seconds or (b) looked for 40 cumulative seconds.

Two observers monitored the infants' looking behavior through peepholes in large cloth-covered frames on either side of the apparatus. The primary observer's responses determined when a trial ended. Interobserver agreement in this and the following experiment averaged 95% per trial per infant.

Preliminary analyses revealed no significant interaction involving condition, trial (see the next paragraph), and sex; the data were therefore collapsed across sex in subsequent analyses.

Results and Discussion

The infants' looking times during the main-trial portion of the test trial (Fig. 2) were analyzed by a 2 × 2 analysis of variance (ANOVA) with condition (occlusion-covering or display-covering) and trial (short-cover or tall-cover) as between-subjects factors. The analysis revealed a significant main effect of trial, $F(1, 32) = 6.88$, $p < .025$, and a significant Condition × Trial interaction, $F(1, 32) = 4.17$, $p < .05$. Planned comparisons indicated that in the occlusion-covering condition, the infants who received the short-cover trial ($M = 24.5$ s) looked reliably longer than those who received the tall-cover trial ($M = 13.4$ s), $F(1, 32) = 10.89$, $p < .0025$, Cohen's $d = 1.5$; in the display-covering condition, the infants who received the short-cover trial ($M = 16.7$ s) and the tall-cover trial ($M = 15.4$ s) looked about equally, $F(1, 32) = 0.17$, $d = 0.2$. Wilcoxon rank-sum tests confirmed these results (occlusion-covering: $W_s = 57, p < .025$; display-covering: $W_s = 79, p > .10$).

In the occlusion-covering condition, the infants who were tested with the short cover looked reliably longer than those tested with the tall cover. In contrast, the infants in the display-covering condition looked about equally regardless of the cover. These results suggest that the infants in the occlusion-covering condition (a) included information about the heights of the cover and object in their representation of the occlusion event; (b) included this same information in their representation of the covering event; and hence (c) detected the violation in the short-cover trial. A single, brief exposure to the occlusion event was thus sufficient to induce the infants to detect the height violation in the covering event—several months before infants ordinarily detect such a violation.

EXPERIMENT 2

In Experiment 2, we sought to confirm the results of Experiment 1 and addressed several additional issues. First, would positive results still be obtained if the occlusion and covering events involved different objects? In Experiment 2, a second object was placed between the cover and tall object. The cover was slid in front of this second object in the occlusion event and was lowered over the tall object in the covering event (Fig. 3).

Second, the infants in the occlusion-covering condition of Experiment 1 might have responded differently in the tall- and short-cover trials simply because of differences in the end points of the occlusion and covering events. In the tall-cover trial, the object became fully hidden in the occlusion and covering events. In the short-cover trial, in contrast, the object became partly hidden in the occlusion event but fully hidden in the covering event (Fig. 1); this difference might have elicited greater attention. We addressed this concern by making the second object in Experiment 2 very short (it resembled the lower part of the tall object and, like it, was 6.5 cm in diameter and 8 cm tall). The end points of the occlusion and covering events were thus similar in that the object always became fully hidden.

Third, the account presented earlier suggests that, although seeing an occlusion event prior to a covering event might induce 8-month-olds to include height information in their representation of the covering event, seeing another covering event should not (because infants this age have not yet identified height as a covering variable). To examine this prediction, we included a covering-covering condition, in which infants saw the cover being lowered over the short and then over the tall object (Fig. 3).

The final goal of Experiment 2 was to determine whether results similar to those of Experiment 1 would be obtained with a modified, within-subjects procedure, described in the following section.

Method

Participants

Participants were 24 infants, 13 male and 11 female (M = 8 months 16 days; range = 7 months 24 days to 9 months 0 days). Another 9 infants were eliminated, 3 because they looked for the maximum time, or nearly the maximum time, allowed in both test trials; 3 because of parental interference; and 3 because the differences in their looking times during the two test trials were more than 3 standard deviations from the mean of their condition. Half of the infants were assigned to the occlusion-covering condition, and half to the covering-covering condition.

Procedure

The infants in the occlusion-covering condition received both a short-cover trial and a tall-cover trial; order was counterbalanced across infants. At the start of each trial, the experimenter's hand grasped the cover and maintained this position until the infant had looked at the scene for 3 cumulative seconds. Because the infants received two trials, and because the occlusion and covering events in each trial involved different objects, we were concerned that this task might prove more difficult than that in Experiment 1; to alleviate this potential difficulty, we showed the occlusion and covering events repeatedly. In each trial, the hand slid the cover in an arc in front of the short object and then slid it back to its original position; this sequence was repeated three times (pretrial). Next, the cover was lowered over the tall object and then returned to its starting position; this sequence was repeated until the trial ended (main trial). The infants in the covering-covering condition received similar trials, except that the hand lowered the cover over the short object in the pretrial.

Each main trial ended when the infant (a) looked away from the event for 2 consecutive seconds after having looked at it for at least 8 cumulative seconds or (b) looked for 80 cumulative seconds. The 8-s minimum value ensured that the infants had the opportunity to observe that the tall object became fully hidden under either cover.

Preliminary analyses revealed no significant interaction involving condition, trial, and either sex or order; the data were therefore collapsed across sex and order in subsequent analyses.

Results and Discussion

The infants' looking times during the main-trial portion of each test trial (Fig. 2) were analyzed by a 2×2 ANOVA with condition (occlusion-covering or covering-covering) as a between-subjects factor and trial (short-cover or tall-cover) as a within-subjects factor. The analysis revealed a significant Condition $\times$ Trial interaction, $F(1, 22) = 17.47, p < .0005$. Planned comparisons indicated that the infants in the occlusion-covering condition looked reliably longer during the short-cover trial ($M = 43.0$ s) than the tall-cover trial ($M = 26.5$ s), $F(1, 22) = 18.72, p < .0005$, $d = 1.2$, whereas those in the covering-covering condition looked about equally during the short-cover ($M = 25.9$ s) and tall-cover ($M = 32.0$ s) trials, $F(1, 22) = 2.51, p > .10, d = 0.5$. Wilcoxon signed-ranks tests confirmed these results (occlusion-covering: $T = 74, p < .005$; covering-covering: $T = 55.5, p > .10$).

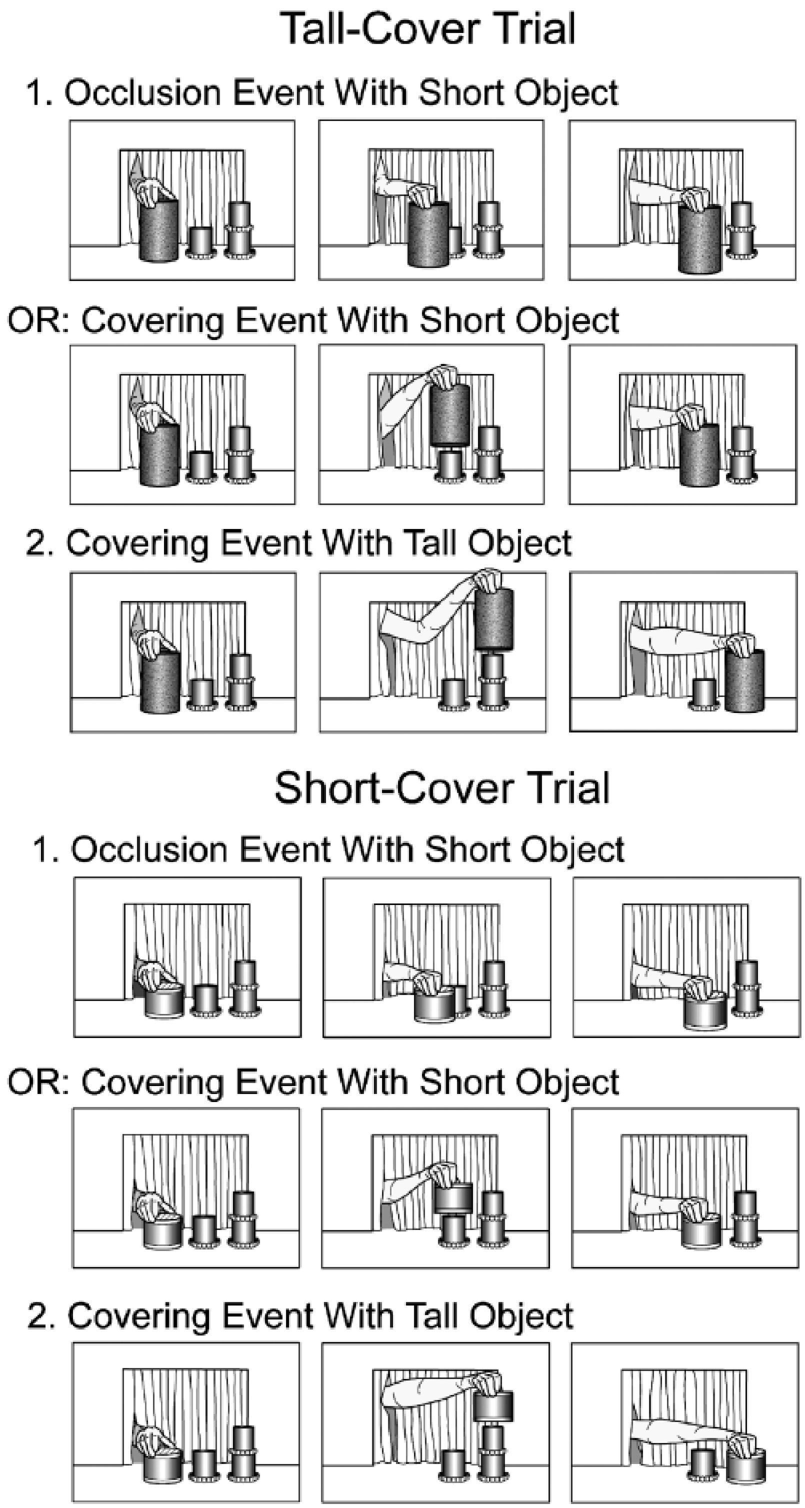

Fig. 3. Test trials in the occlusion-covering and covering-covering conditions of Experiment 2. The infants first saw an occlusion or a covering event with the short object and then a covering event with the tall object; the cover was either tall (top panel) or short (bottom panel). To start, the hand either slid the cover in front of the short object or lowered it over the short object (2 s). After a 3-s pause, the hand returned the cover to its initial position (2 s), paused for 1 s, and then repeated this 8-s sequence two more times. Next, the hand lifted the cover (2 s), moved it to the right (1 s), and lowered it over the tall object until it became fully hidden (3 s). After a 1-s pause, this sequence was performed in reverse. The covering event was repeated until the trial ended.

These results provide further evidence that (a) infants can represent key information about a variable they have not yet identified for an event category if they are first exposed to an event from a different category in which this variable has been identified, and (b) prior exposure to an event in which the variable has not been identified has no facilitating effect. The results also indicate that, for a positive result to be obtained, the two events need not involve exactly the same objects: In the occlusion-covering condition, the short cover was slid in front of the short object and then lowered over the tall object, and the infants still detected the violation in the covering event.

Further Results

Would infants still succeed in the occlusion-covering condition if the short and tall objects were perceptually less similar? To address this question, we tested 14 infants (M = 8 months 15 days; range = 7 months 24 days to 9 months 0 days) in a different-color condition identical to the occlusion-covering condition except that the short object was not red, like the tall object: Instead, it was blue (6 infants) or yellow (8 infants). Another 2 infants were eliminated because they looked nearly for the maximum time allowed in both test trials.

The infants' looking times in the different-color condition were compared with those in the occlusion-covering condition of Experiment 2, by a 2 $\times$ 2 ANOVA with condition (occlusion-covering or different-color) as a between-subjects factor and trial (tall-cover or short-cover) as a within-subjects factor. The analysis revealed a significant Condition $\times$ Trial interaction, $F(1, 24) = 5.09$, $p < .05$. Planned comparisons indicated that, whereas the infants in the occlusion-covering condition looked reliably longer during the short-cover trial than the tall-cover trial, $F(1, 24) = 6.31$, $p < .025$, $d = 1.2$, those in the different-color condition looked about equally during the short-cover (M = 34.8 s) and tall-cover (M = 38.5 s) trials, $F(1, 24) = 0.37$, $d = 0.2$.

These results make clear that exposure to an event in which a variable has been identified enhances infants' processing of a subsequent event only if the two events involve highly similar objects. Changing the color of the short object eliminated the facilitating effect of the occlusion event.

GENERAL DISCUSSION

Infants younger than 12 months typically do not represent height information in covering events: They are not surprised when a short cover is lowered over a tall object until it becomes fully hidden (Wang et al., 2005). However, 8-month-olds detect this violation if the cover is first placed in front of the object or a similar object. This finding is consistent with the reasoning account we presented earlier. Because 8-month-old infants have already identified height as an occlusion variable (e.g., Baillargeon & DeVos, 1991), infants of this age include height information in their representation of the occlusion event; this information remains available, or is again included, when the infants represent the subsequent covering event, and they are therefore able to detect the violation in the event.[5] For this positive result to be obtained, only a very brief exposure is required (e.g., less than 10 s in Experiment 1); furthermore, the occlusion and covering events can be embedded in a continuous event sequence. These results underscore the remarkable flexibility of infants' representation process.

What is the specific mechanism responsible for the effect demonstrated here? A first possibility involves rapid training (e.g., Baillargeon, 1998; Johnson, Amso, & Slemmer, 2003; Newcombe, Sluzenski, & Huttenlocher, 2005; Wang & Baillargeon, 2005; Wilcox & Chapa, 2004; for a related review, see Scholl, 2004). Infants' exposure to an event in which they have identified a variable may accelerate their acquisition of the same variable in a different event, especially when the two events involve the same or similar stimuli. Thus, attending to the height information in the occlusion event might have helped the infants in Experiments 1 and 2 recognize the relevance of this information to the covering event. This new height variable, identified on-line, would have allowed the infants to detect the violation in the short-cover trial.

A second possibility builds on a model of object-based attention in infants (e.g., Leslie, Xu, Tremoulet, & Scholl, 1998; Scholl & Leslie, 1999; for related models of visual attention in adults, see, e.g., Kahneman, Treisman, & Gibbs, 1992; Pylyshyn, 1989, 1994; Treisman & Gormican, 1988). According to this model, when watching an event involving a few objects, infants assign an index to each object. These indexes serve as pointers that help keep track of the objects through displacements and occlusions. Typically, indexes are assigned on the basis of spatiotemporal information and contain no featural information; however, such information can be added through a binding process. The model suggests that the infants in Experiment 1, when watching the occlusion event, bound height information to the indexes assigned to the cover and object; because the infants continued to use the same indexes when watching the covering event, this height information became, fortuitously, available to them. (To explain the results of Experiment 2, we need the further, plausible assumption that infants who bind variable information to one object may also bind this information to a nearby, highly similar object.)

Whichever possibility turns out to be correct, the present research makes clear how flexible and dynamic are infants' representations of events: A very brief experience—as long as it is the right experience—can alter their representations of subsequent events and allow them to detect violations they would not other-

[5]Similar effects should be observed when the initial event comes from another category, as long as the variable height has been identified as relevant to that category. For example, infants identify height as a containment variable at about the age of 7.5 months (Hespos & Baillargeon, 2001). Thus, after seeing a tall object being placed inside a short container, 8- but not 6-month-olds might detect a violation when the container is next turned upside down and lowered over the object until it becomes fully hidden.

wise detect. The present research thus offers a promising approach for understanding how infants represent events, and how these representations change with knowledge and experience.

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