JOURNAL OF COGNITION AND DEVELOPMENT
2017, VOL. 18, NO. 2, 289–308
http://dx.doi.org/10.1080/15248372.2017.1281279



# Enhancing Young Infants' Representations of Physical Events Through Improved Retrieval (Not Encoding) of Information

Su-hua Wang[a] and Kristine H. Onishi[b]

[a]University of California Santa Cruz; [b]McGill University, Canada

**Abstract**

Infants' representations of physical events are surprisingly flexible. Brief exposure to one event can immediately enhance infants' representations of another event. The present experiments tested two potential mechanisms underlying this priming: enhanced encoding or improved retrieval. Five-month-olds saw a target block become hidden inside a container, followed by priming events that involved a second block. The target was subsequently withdrawn from the container. Infants noticed a change to the target's height after seeing priming events involving occlusion, but they failed to so do if priming events involved no occlusion (Experiment 1). Infants noticed the change even when the priming and target blocks were not identical (Experiment 2). Because the target became fully hidden before the priming events started, priming must have arisen from improved retrieval, not enhanced encoding, of information about the target. The results add to our understanding of how brief observation of one event can affect infants' processing of subsequent events, thereby elucidating fine-grained aspects of the representational process.



Children's ability to represent objects and events undergoes remarkable developments during their 1st years of life. A number of theoretical views can account for these developments. Some of the views focus on causal analysis and rule learning (e.g., Gopnik, 2012; Gopnik, Griffiths, & Lucas, 2015; Leslie, 2004; Wang, Zhang, & Baillargeon, 2016), whereas others focus on processing constraints and contextual details (e.g., Bearce & Rovee-Collier, 2006; Duh & Wang, 2014; Kwon, Luck, & Oakes, 2014; Ross-Sheehy, Oakes, & Luck, 2003). The present research used a new priming task to examine the mechanisms underlying infants' representations of physical events.

Observing specific types of events can produce immediate enhancement of infants' processing of subsequent events; for example, seeing occlusion events can prime processing of containment events, just as seeing the word "nurse" can prime processing of the word "doctor" (e.g., Meyer & Schvaneveldt, 1971). For words, one hypothesized mechanism is that activation spreads from one word to other words with similar or related meanings within a network of word representations (e.g., Collins & Loftus, 1975). Here we borrow a general definition of priming and refer, descriptively, to the change in processing of stimuli (usually enhanced processing) caused by immediate prior experience. However, for processing of physical events, rather than spreading activation, one of the proposed mechanisms is carryover (Baillargeon et al., 2012).

**CONTACT** Su-hua Wang suhua@ucsc.edu Department of Psychology, University of California, 1156 High Street, Santa Cruz, CA 95064, USA.

According to this account, carryover stems from a unique characteristic of infants' approach to learning about physical events. Empirical evidence supports that infants sort physical events into distinct categories (Casasola & Cohen, 2002; Casasola, Cohen, & Chiarello, 2003; Rigney & Wang, 2015), where an event category represents a type of spatial interaction in which objects serve distinct roles (e.g., occluder, occludee). For example, whether infants categorize an event as occlusion or containment depends on whether the event involves hiding an object *behind* or *inside* another object. Moreover, infants' expectations about one event category are often not generalized to another (Hespos & Baillargeon, 2001, 2006; Sitskoorn & Smitsman, 1995; Wilcox, 1999); as a result, age gaps often separate infants' use of the same object information across different event categories. For example, 3.5-month-olds readily notice implausible *occlusion* events where tall objects become fully hidden behind short occluders (e.g., Baillargeon & DeVos, 1991), but they fail to notice implausible *containment* events where tall objects become fully hidden inside short containers until they are several months older (e.g., Hespos & Baillargeon, 2001).

Although event categories seem to be distinct, infants' representation of object information for one category can be temporarily transferred (or carried over) to another category (e.g., Wang & Baillargeon, 2005; Wilcox & Chapa, 2004; Wilcox, Woods, & Chapa, 2008). For example, at 4.5 months, infants typically fail to notice the improbable outcome when a tall object becomes fully hidden inside a short container. However, watching occlusion events in which the object moves in front of the container induces infants to detect the violation in containment events (Wang, 2011). Thus, watching an event from a category in which infants typically encode and retrieve information about object height primes their detection of violations in another category of events through the transfer (or carryover) of height information from one event representation to another (Baillargeon et al., 2012).

Priming showcases the remarkable flexibility of the representational process in infancy and demonstrates that brief experience with one type of event can exert immediate effects on infants' processing of another type of event. Potentially, carryover can be distinguished from general priming in terms of its underlying process: As has been proposed, carryover may stem from the automatic transfer of the content in the representation of one event to the representation of another event (Baillargeon, Li, Ng, & Yuan, 2009; Wang, 2011; Wang & Baillargeon, 2005). However, the precise mechanism for the cross-category priming effects is still an open question. Knowing when priming arises will shed light on the processes underlying infants' representations of physical events and will specify the ways in which learning may take place—for example, when infants observe a series of events across different categories.

The most complete account specifying how infants represent physical events is the *systems* account, a model that proposes that multiple computational systems work in tandem to build representations of physical events (e.g., Baillargeon, Li, Gertner, & Wu, 2011; Wang & Baillargeon, 2008a). Of importance for the current question are two systems. The *object-representation system* handles information about object features by encoding and maintaining information about those features and allowing infants to recognize objects over time. As with adults, intervening events or experiences can affect infants' maintenance of the encoded information and potentially alter the encoded information before it is retrieved (Carey & Xu, 2001; Huttenlocher, Duffy, & Levine, 2002; Needham, 1998). The *physical-reasoning system* builds representations of ongoing physical events, including retrieving, from the object-representation system—information about objects deemed relevant for the representation of the event. This system allows infants to predict the outcomes of physical events involving object interaction—for example, whether an object will be fully or partly hidden by another object (Baillargeon et al., 2012; Luo, Kaufman, & Baillargeon, 2009; Wang & Baillargeon, 2008a). According to the systems account, as infants learn what *variables* (object features such as shape, height, and weight) are relevant for an event category, the physical-reasoning system becomes better at retrieving information relevant to the current event, thereby improving predictions for the outcomes of physical events.

One crucial aspect of the systems account is the division of labor between systems: For tasks that involve no object interaction, the object-representation system operates; for tasks involving object interaction, the physical-reasoning system operates (and the object-representation system may be called upon). Because of the divide, infants may use a specific type of variable information (e.g., height) successfully during one type of task while failing to do so in the other type of task. For example, 11-month-olds who had just failed to detect a change in an object's height when tested with an event in which the object was briefly covered by another object (evidence for failed use of height information by the physical-reasoning system) were able to distinguish between both the prechange and postchange objects from an novel object solely by height when tested using a static display of objects (evidence for successful use of height by the object-representation system; Wang & Mitroff, 2009).

It has been shown that 3.5-month-olds notice implausible outcomes when a tall object becomes fully hidden *behind* a short box, whereas 6.5-month-olds fail to do so when the tall object becomes fully hidden *inside* the short box (e.g., Hespos & Baillargeon, 2001, 2006). According to the systems account, infants' failure to notice implausible containment events can arise from at least two potential sources: (a) a failure of the object-representation system to *encode* object height, and/or (b) a failure of the physical-reasoning system to *retrieve* height information from the object-representation system. That is, what might be enhanced in the situations where priming is observed can be (a) the object-representation system's encoding of information, and/or (b) the physical-reasoning system's retrieval and use of that information. The present research sought to distinguish between the two possibilities.

Previous research has shown that when 4.5-month-olds saw an occlusion event followed by a containment event, they noticed violations in height during the containment event; however, without priming by the occlusion event, infants this age typically fail to notice the violation (Wang, 2011). In one experiment, a priming object was moved in front of (occlusion event) or next to (non-occlusion event) a container and returned to its original position; next, the target object was lowered into a container that was too short to fully hide it. When the target became fully hidden inside the very short container, 4.5-month-olds noticed the violation only after seeing the occlusion (but not the non-occlusion priming), demonstrating the effect of occlusion priming on infants' processing of the containment event. However, because the occlusion event occurred before the containment event began, seeing occlusion might have enhanced the *encoding* of information about the target object's height in the first place. Thus, the existing work cannot fully distinguish between the encoding and retrieval hypotheses—a gap we sought to fill with the current research.

In the present experiments, we used a priming task in which infants were tested on whether they noticed a change in an object's height. Infants saw two events, each composed of three segments: (1) A target block was inserted into a taller box and became fully hidden,

(2) a second block was manipulated during a priming event, and (3) the target block was withdrawn from the box, revealing either the same or a different block. Critically, the target object was fully hidden before the priming segment began. The design of the segments thus prevented priming from enhancing infants' encoding of the target's height and allowed us to distinguish between the encoding and retrieval hypotheses. Thus, in the current research, we built on previous work using infants' sensitivity to a change in an object as a tool to examine whether they represented and used specific information about the object (e.g., Duh & Wang, 2014; Wang & Baillargeon, 2006, 2008b).

In Experiment 1, infants saw the beginning of a target event in which a short target block was lowered into a box. Next, one group of infants saw an *occlusion* priming event in which the priming block moved side to side behind the box; the other group of infants saw a *non-occlusion* priming event in which the priming block moved forward and back next to the box. Finally, infants were shown the end of the target event in which the target block was withdrawn from the box and either remained short or became as tall as the block used in the priming segment. If watching occlusion enhanced infants' sensitivity to the height change in the containment event even when encoding could no longer be affected, priming must have occurred through enhancing retrieval of information. Conversely, failure to observe priming would be consistent with the encoding hypothesis.

Examining whether infants notice the change to an object's height distinguishes our research from the existing work that examined priming only on infants' detection of interaction violations—violations that occur during the interaction between objects (Wang, 2011; Wang & Baillargeon, 2005; Wilcox & Wood, 2009). To detect interaction violations, infants must notice only that something impossible is occurring at the moment (e.g., a very tall object is being withdrawn from a short container). To detect object changes, infants must at least encode the initial object feature, encode the final feature, and compare the two (Hollingworth, 2003; Mitroff, Simons, & Levin, 2004). In addition, infants must maintain the featural information in memory throughout the task, with the possibility that intervening events or experiences can alter this information before it is retrieved. Directly testing whether infants notice object changes, our task serves as a stringent test of infant memory for object features and helps bridge the literatures of physical reasoning and memory development (e.g., Fagan, 1974; Rose, Feldman, & Jankowski, 2004; Rovee-Collier & Cuevas, 2009).

## Experiment 1

Five-month-old infants received two test trials in which a short block (the target) was inserted into a taller container and became fully hidden. When the target was completely out of view, infants were shown a priming event in which a second block was slid side to side *behind* the container (occlusion condition; Figure 1). Next, the target was withdrawn from the container. When revealed, the target was either the same height (no-change event) or twice as tall as before (change event). The two potential mechanisms, encoding and retrieval, predicted different results for this condition. As the target was no longer available for further encoding when infants saw the occlusion events, the encoding hypothesis predicted that infants' detection of the target's height change would not be enhanced. In contrast, the retrieval hypothesis predicted carry-over to arise in this condition as the priming event occurred before the prechange

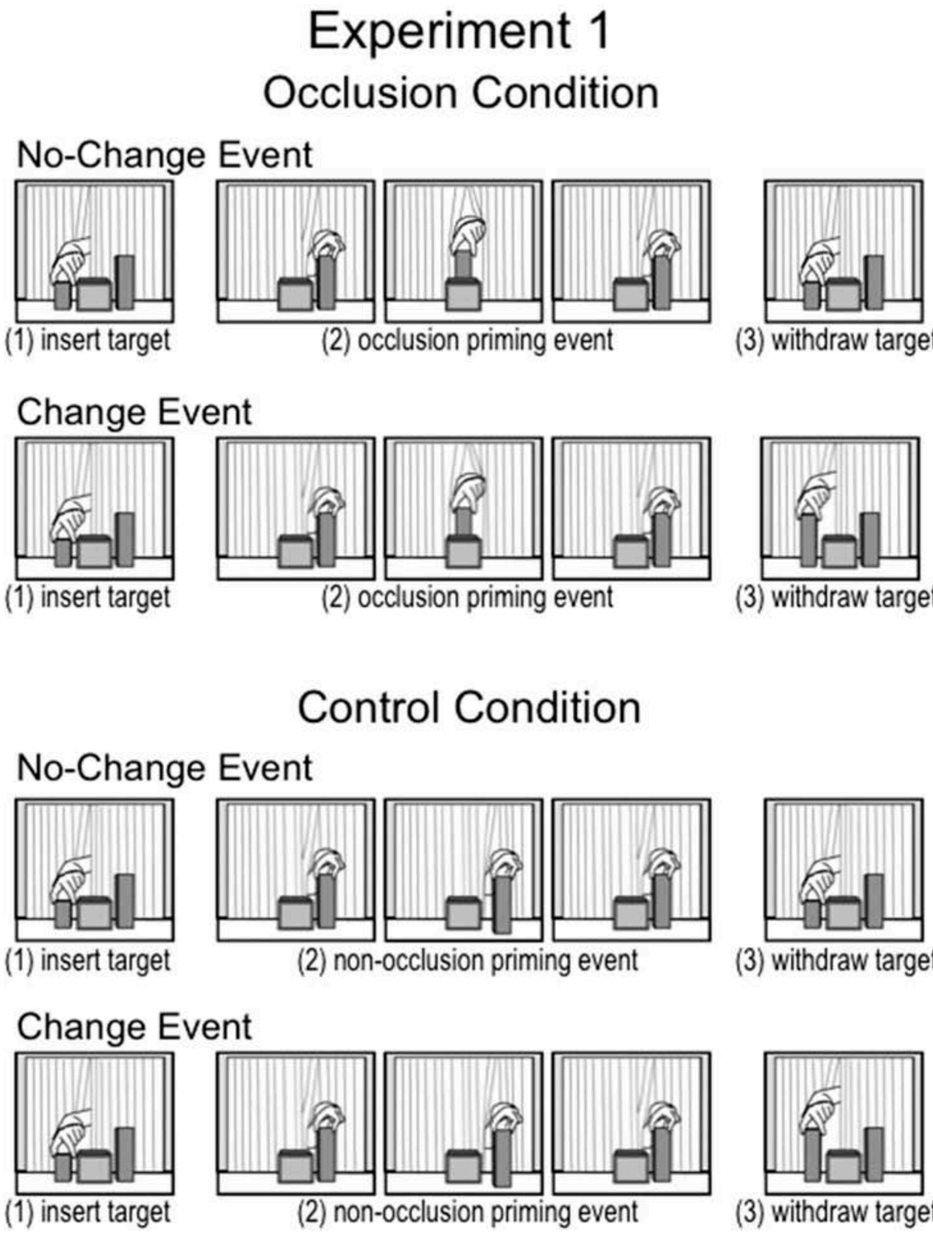


**Figure 1.** Schematic depiction of the no-change and change events in the occlusion and control conditions of Experiment 1.

information needed to be retrieved. Thus, the retrieval hypothesis predicted that the 5-month-olds would detect the change to the target's height and look longer at the change event than the no-change event because occlusion triggers carryover of the height information. However, this positive result was subject to an alternative explanation that watching any type of intervening event would have induced carryover.

A control condition was conducted in which a different group of 5-month-old infants saw an alternative, priming event that involved a spatial relation that was not occlusion. Specifically, the infants in the control condition watched similar event sequences, except that the priming block was slid forward and back *next to* the container during the priming event (non-occlusion condition; Figure 1). Infants' looking times were measured to determine whether they detected the change in the height of the target object. For the control condition, the systems account predicted that there should be no carryover (and hence no priming) in the absence of occlusion priming (and indeed, similar results have been found with 8-month-old infants; Wang & Baillargeon, 2005). Because infants at this age typically fail to detect interaction violations involving height in containment events (Hespos & Baillargeon, 2001, 2006; Wang, 2011), the control group should miss the change and look equally at the change and no-change events.

The design of the control condition could give rise to another potential issue. In the occlusion condition, the priming block interacted with the container as it moved in a plane behind the container. In the control condition, the movement of the priming block could be seen as completely independent of the container; the lack of object interaction could reduce the visual appeal of the events, resulting in infants' overall disengagement in the task and their insensitivity to *any* change to the target. To address this issue, a third condition was conducted to verify that infants would be able to detect some type of change after watching potentially less interesting priming events that involved no object interaction. Specifically, we sought to confirm that infants would detect a change to the target's *shape* after watching non-occlusion priming events (shape condition; Figure 2).

Shape was chosen because by 4.5 months, infants have been shown to individuate objects of different shapes in occlusion events (Wilcox, 1999; see also Needham, 1999), though it is unclear whether infants do so in containment events. If non-occlusion priming events in the control condition rendered infants insensitive to any changes, the infants in the shape condition should fail to detect the shape change and look equally at the no-change and change events.

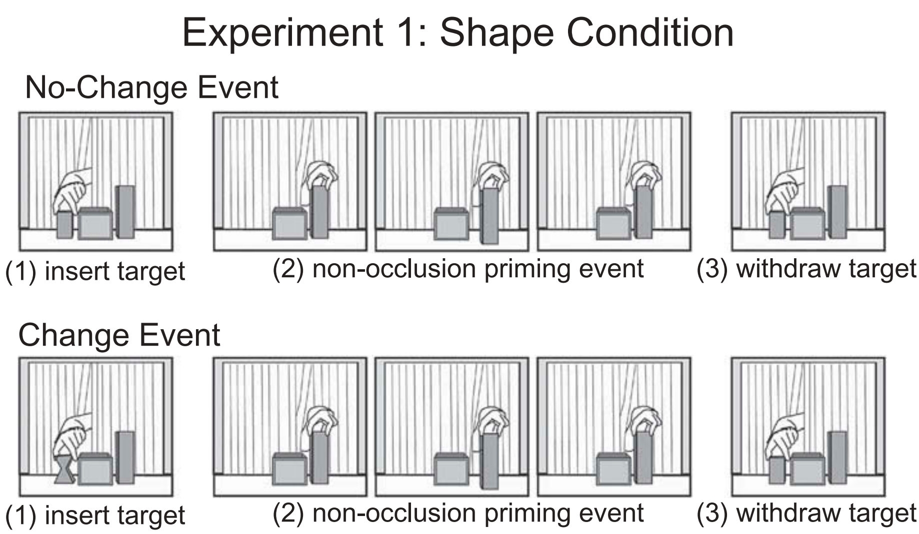


**Figure 2.** Schematic depiction of the no-change and change events in the shape condition of Experiment 1.

## Method

### Participants

Experiment 1 included 48 healthy-term infants, ranging in age from 4.1 months to 5.9 months ($M_{age}$ = 5.1 months; 23 female, 25 male).[1] The age was chosen based on the previous findings that infants at this age detect interaction violations involving height in occlusion events but not containment events (Hespos & Baillargeon, 2001, 2006; Wang, 2011).

The infants were assigned to one of three conditions: occlusion ($M_{age}$ = 4.8 months), control ($M_{age}$ = 5.2 months), or shape ($M_{age}$ = 5.3 months). An additional 15 infants were tested, but their data were excluded due to parental interference (1), failure to complete both trials (11), distraction that ended the trial (2), or a looking-time difference of more than 4 standard deviations from the mean difference for the condition (1). Participants received a small gift or travel reimbursement but were not otherwise compensated for participation.

### Apparatus and stimuli

All events were presented in a wooden display box (104 cm wide × 90 cm high × 58 cm deep) mounted at the infant's eye level. The side and back walls were white, and the floor was covered with pastel-patterned contact paper. In front of the display box was a large opening (97 cm × 48 cm); between trials, a curtain (100 cm × 61 cm) was lowered to conceal the opening. On the back wall, a window (48 cm × 34 cm), filled with white fringe, allowed the experimenter's hand to reach inside the opening to present the events. A fabric-covered wood frame (64 cm × 182 cm) was hinged to each side of the display box, thereby isolating the infant from the rest of the testing room. Each of the frames had a peephole (1 cm in diameter), through which observers monitored the infant's eye gaze while remaining hidden from the infant.

The stimuli included a target block, a priming block, and a container, each made of foam core covered with contact paper. The target block (9 cm tall × 5 cm wide × 5 cm deep) was a rectangular prism covered with wood-patterned contact paper. The priming block was similar to the target, except for its height (18 cm tall). The container (11 cm wide and 10 cm deep) was a rectangular box covered with green contact paper with its edges trimmed with green electrical tape. The front of the container was 9.5 cm tall, and to make it clear that it was a container, the back wall was 1 cm taller (10.5 cm); the side walls angled slightly to join them. Each wall was 0.5 cm thick, and the interior of the container was white.

### Events

Each infant saw two test events (change, no-change; Figures 1 and 2). They were randomly assigned one of two test-event orders, a no-change event first or a change event first, in one of the three conditions: occlusion, control, or shape. A metronome beat once per second to ensure that the experimenters kept to their scripts. In the following sections, events are described from the infant's point of view.

[1]Across experiments, approximately 75% of the participants were recruited from Santa Cruz, CA and the rest were recruited from Montréal, Quebec. There were slight differences in the apparatus used in the two locations, but experimental stimuli were identical. For Experiment 1, an analysis of variance with Location (1, 2) × Condition (occlusion, control, shape) × Order (change, no-change first) × Event (change, no-change) did not reveal any effect involving location, $Fs < 1.38$, $ps > .25$. Therefore, we collapsed across this factor throughout the analyses.

***No-change event.*** When the curtain was raised, infants could see the container, 35 cm from the right wall and 23 cm from the front edge. The target block stood 2.5 cm to the left of the container, and the priming block stood 2.5 cm to the right. Both blocks were centered between the front and back of the container. The primary experimenter's bare left hand grasped the top of the target, with the thumb on the left and the index finger on the right side of the target. The event, though continuous, can be considered as composed of three segments.

During Segment 1, the target was inserted into the container. Specifically, after infants had accumulated 2 s of looking at the static scene (allowing them to encode information about the stimuli), the primary experimenter (E1) lifted the target (2 s) until its base was 2.5 cm above the top of the container, moved the target to the right about 10.5 cm until it was centered above the container (1 s), and then inserted it into the container until its base touched a trap door at the bottom of the container (2 s). Next, E1 released the target and grasped the top of the priming block (1 s).

During Segment 2, the priming event (18 s) was presented after infants accumulated 2 s of looking at the final paused scene of Segment 1. In the *occlusion* condition, E1 slid the priming block toward the back wall until its front edge was 3 cm behind the back edge of the container (1 s). Next, E1 slid the priming block to the left about 21 cm until it was past the left edge of the container (1 s), paused (1 s), slid the priming block to the right 21 cm (1 s), and then paused again (1 s). The 4-s left–right cycle was repeated four times (for a total of 16 s), resulting in four repetitions of the occlusion event. Finally, E1 slid the priming block forward to its initial position, centered to the right of the container (1 s), and paused.

In the *control* and *shape* conditions, the 4-s cycles of Segment 2 were modified: Instead of left and right behind the container, the priming block was slid forward and back next to the container for a *non-occlusion* priming event. First, as in the occlusion condition, it was slid back until its front edge was 3 cm behind the back edge of the container (1 s). Next, instead of sliding the priming block left to right, E1 slid it forward about 21 cm until its back was 3 cm past the front edge of the container (1 s), paused (1 s), slid the block back 21 cm (1 s), and paused (1 s). The 4-s front–back sequence was repeated four times. Finally, E1 returned the block to its initial position. Thus, the infants in the control and shape conditions watched the priming block being slid over the same distance and for the same amount of time as in the occlusion condition—except that the block was never occluded by the container. In all conditions, the target remained completely out of view for at least 20 s (i.e., the initial paused scene for at least 2 s plus the priming events for 18 s).

During Segment 3, infants watched the target being withdrawn from the container. Specifically, after infants accumulated 2 s of looking at the final paused scene of Segment 2, E1 released the priming block, inserted her hand into the container to grasp the top of the target (1 s), lifted it until its base was 2.5 cm above the top of the container (2 s), moved it to the left 10.5 cm until it was above its original position to the left of the container (1 s), and then lowered it to the floor (2 s). E1 then paused while continuing to grasp the top of the target until the trial ended (see the Procedure section). Infants' looking times at this final paused scene were used as the dependent measure.

***Change event.*** Infants in the occlusion and control conditions saw the same change event, which was similar to the no-change event—except that at the end of Segment 3, when the target was withdrawn from the container, it was twice as tall as before (18 cm). The design was slightly different in the shape condition: A target shaped like an hourglass (9 cm tall, 5 cm wide, 5 cm deep, with its center narrowed to about 1 cm in diameter) was inserted into the container (in Segment 1), and the 9-cm rectangular block was withdrawn so that only the shape (not height) of the target was changed.[2]

### Procedure

Each infant received two test trials; the change event was shown in one trial and the no-change event was shown in the other trial. Half of the infants in each condition saw the change event first and half saw the no-change event first. The infants were tested in a brightly lit room. Each infant sat on a parent's lap approximately 45 cm from the display box. Parents were asked to remain quiet and to keep their eyes closed during the trials.

For both the change and no-change events, a second experimenter (E2) sat beneath the display box. After the target was placed inside the container, E2 opened a trap door under the target, removed and replaced it with either the same block (no-change event) or the different block (change event). When placed inside the container, markings on the interior wall of the container and on the back of the target allowed E2 to ensure that the top of the target, whether short or tall, was at the same level as the target when it had been initially inserted and released.

Two independent observers, unable to see the events and blind to the design, watched infants through the peepholes in the fabric-covered frames on either side of the display box. Each observer held a controller linked to a computer running Windows-based software and pressed a button when the infant looked at the scene. Each trial ended (a) when infants looked away from the final paused scene for 1 consecutive second after having looked at it for at least 5 cumulative seconds, or (b) when they had looked at the scene for 30 cumulative seconds. Reported looking times were based on input from the primary (typically more experienced) observer. To assess interobserver agreement, infants' looking times at the final paused scene of each trial were divided into 100-ms intervals. Percent agreement was calculated by dividing the number of intervals in which the observers agreed whether the infant was looking at the scene or not by the total number of intervals during this portion of the trial. Agreement in this experiment and the following experiment was measured for all but two infants (only one observer was present for two infants) and averaged 91% ($SD$ = 7%) across trials and across infants.

In this experiment and the following experiment, preliminary analyses revealed no reliable interactions involving event (change or no-change) and either order (change or no-change event first) or sex, $F$s < 2.41, $p$s > .10. Therefore, the data were collapsed across order and sex in subsequent analyses.

[2]The primary goal of Experiment 1 was to compare the occlusion and control conditions, while testing for priming effects and examining whether it was the occlusion component that produced the effects. Thus, the two conditions were designed to be identical except for the priming portion, which was methodologically appropriate to test our hypothesis. However, it would have been ideal to equate the end state of the two test events across conditions—for example, for the postchange target to be the 9-cm block while manipulating the prechange target as in the shape condition. We applied this approach in Experiment 2.

## Results

First, we tested whether the height change would be detected after infants watched the occlusion priming events. The infants' looking times at the final paused scene of the events (Figure 3) were compared by a 3 × 2 mixed-model analysis of variance (ANOVA), with condition (occlusion, control, or shape) as a between-subjects factor and event (change or no-change) as a within-subject factor. The analysis yielded a significant main effect of event, $F(1, 45) = 10.48$, $p = .002$, $\eta_p^2 = .19$. Importantly, the Condition × Event interaction was significant, $F(2, 45) = 3.51$, $p = .038$, $\eta_p^2 = .14$, suggesting that infants' looking-time patterns differed across conditions.

Planned pairwise contrasts indicated that infants in the occlusion condition looked significantly longer at the change event ($M = 13.6$ s, $SD = 7.1$ s) than the no-change event ($M = 8.6$ s, $SD = 3.6$ s), $F(1, 45) = 11.97$, $p = .001$, Cohen's $d = 0.67$, whereas those in the control condition looked about equally at the change event ($M = 8.8$ s, $SD = 3.8$ s) and the no-change event ($M = 9.1$ s, $SD = 3.5$ s), $F(1, 45) < 1$, $d = 0.06$, suggesting that only the occlusion priming events enhanced infants' change detection. The control group's apparent failure to detect the change was not because they had watched disengaging priming events; infants in the shape condition who saw the same priming events detected the shape change as indicated by their longer looking at the change event ($M = 12.6$ s, $SD = 6.5$ s) than the no-change event ($M = 9.3$ s, $SD = 5.4$ s), $F(1, 45) = 5.47$, $p = .024$, $d = 0.78$. The results from the ANOVA were consistent with infants' individual responses: Twelve of 16 infants in the occlusion condition and 13 of 16 infants in the shape condition looked longer at the change event than the no-change event, $ps < .05$ (binomial tests, one-tailed). In contrast, only 9 of 16 in the control condition looked longer at the change event than the no-change event, $p > .40$.

Two additional 2 (condition) × 2 (event) ANOVAs were conducted to directly compare the occlusion condition to the control condition and the control condition to the shape condition. Each analysis yielded a significant Condition × Event interaction, $F(1, 30) = 5.53$ and $F(1, 30) = 5.17$, $\eta_p^2 = .14$ and $\eta_p^2 = .13$, respectively, $p = .026$ and

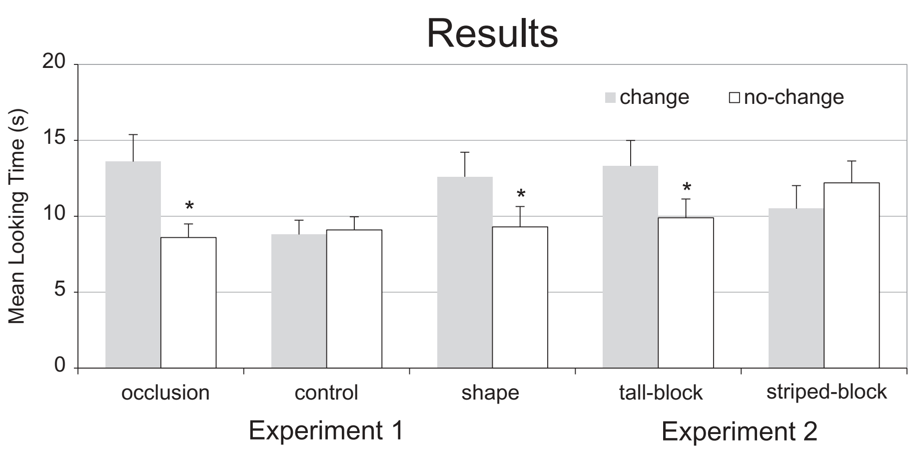


**Figure 3.** Mean looking times of the infants in Experiments 1 and 2 at the change and no-change events. Error bars represent standard errors. An asterisk indicates a reliable difference between the change and no-change events within the condition at $p < .05$.

$p$ = .030. The results confirmed that infants' looking-time patterns differed across two conditions in each comparison.

Finally, we verified that the priming events in the occlusion and control conditions were of roughly equal interest to infants by comparing their total looking times during the 18-s priming portion (Segment 2). A 2 (condition) × 2 (event) ANOVA revealed no reliable effects or interactions, $F$s < 1.57, $p$s > .10. Thus, the infants in both conditions appeared equally attentive to the priming events, whether they involved occlusion or not, and looked at them for almost the entire duration (occlusion, $M$ = 16.4 s, $SD$ = 2.5 s; control, $M$ = 16.1 s, $SD$ = 2.8 s).

## Discussion

Experiment 1 showed that at an age when infants ordinarily fail to notice height changes in containment events, they could be induced to do so through prior exposure to occlusion events. The results are consistent with the systems account, as non-occlusion priming, which might require fewer processing resources, does not lead to enhanced sensitivity to a height change (although it does not impede detection of a shape change). Crucially, the results further clarified whether priming arose from enhanced encoding or enhanced retrieval of object information. Because the prechange target was no longer in view when the priming events started, infants' improved sensitivity to the height change in the containment event (after seeing the occlusion events) could not come from enhanced encoding of the prechange target. Instead, the results are consistent with the idea that infants' improved sensitivity to the height change is derived from enhanced *retrieval* of information. Moreover, we showed that change detection was enhanced by occlusion exposure specifically: Infants noticed the change after seeing occlusion events but failed to notice the change when the events used the same stimuli and lasted the same duration but involved no occlusion.

The infants in the shape condition noticed the change even though they saw the same priming events as did the control group, suggesting that the negative results in the control condition were not due to overall disengagement after seeing a priming event involving no occlusion. A valid point could be raised about the interaction between height and shape: As the height of an object changes, its shape could be perceived as changing as well. For example, as a square object elongates, it becomes rectangular. Previous work has shown that infants readily detect shape violations before height violations (Wilcox, 1999), suggesting that the rules of shape and height may be learned separately in the first months of life. The question of when and how infants begin to notice the interplay between variables such as height and shape, though certainly worthy of investigation, is beyond the scope of the present research. The shape condition in the present experiment, however, demonstrated for the first time that infants at 5 months are sensitive to shape changes in *containment* events.

Finally, previous research has shown that by 6 months, infants encode some object-feature information (Duffy, Huttenlocher, LeVine, & Duffy, 2005) and remember categorically related items for about 15 s (e.g., images of cats or dogs; Oakes & Kovack-Lesh, 2013). In Experiment 1, the 5-month-olds noticed the change when postchange information was provided at least 20 s after the prechange target was last seen. Thus, the present results also provide evidence that by 5 months, infants are capable of maintaining height information in their memory for at least 20 s. However, the point we would like to emphasize from the results of Experiment 1 is that enhanced sensitivity to the change in containment events after seeing occlusion events seems to arise from improved retrieval, rather than enhanced encoding, of height information.

## Experiment 2

An important aspect of the design in Experiment 1 was that the priming block was identical to the postchange target. Research on analogical reasoning, such as the work by Gentner and colleagues, has suggested that perceptual similarity helps children extract relational commonalities among stimuli by facilitating their alignment for comparison and therefore making the mapping between stimuli easier (e.g., Ferry, Hespos, & Gentner, 2015; Gentner, Anggoro, & Klibanoff, 2011). Inspired by these findings, we hoped that using identical priming and target blocks (as in Experiment 1) would help infants link the two objects and thus link the priming and target events. In addition, the prechange target was similar to the container in height, making it possible for infants to use the container as a reference for maintaining the prechange height information (e.g., Duffy et al., 2005; Huttenlocher et al., 2002).

Consistent with the important roles of similarity and comparison (e.g., Gentner, Loewenstein, & Hung, 2007; Gentner & Medina, 1998), the infants in the occlusion condition of Experiment 1 appeared to link the priming and target event by carrying priming event information over to the target event, when the priming and target blocks were identical. In Experiment 2, we explored whether carryover requires these similarities and opportunities for comparison, by (a) making the priming block much taller than the target so that they looked more different from each other, (b) varying additional features between the priming and target blocks, and (c) using a container that was much taller than the target to reduce the utility of its height as a comparison and memory aid.

The use of a taller container also helped rule out an alternative explanation for the results of Experiment 1. In the no-change event of the occlusion and control conditions, when the prechange target (9 cm tall) was inserted into or withdrawn from the container (9.5 cm tall), the interaction between the block and container did not create a violation. However, in the change event, when the postchange target (18 cm tall) was withdrawn, it introduced not only a height change but also an interaction violation, as the 18-cm target should not have been fully hidden in the 9.5-cm container. Thus, the infants in the occlusion condition might have looked longer at the change event not because they detected the impossible *change* to the object between the time it was inserted into and the time it was withdrawn from the container, but because they detected the impossible *interaction* between the container and the postchange target as it was withdrawn. The results of the shape condition mitigated this concern because the change event involved no interaction violation (as both the prechange and postchange targets were shorter than the container), and yet infants still looked longer at the change event. Experiment 2 used a much taller container to remove any interaction violation and directly test the alternative explanation in the case of height.

Five-month-old infants watched two test events as in the occlusion condition of Experiment 1, except that a taller priming block and container were used. The priming block was 30 cm tall (rather than 18 cm), and the container was 19.5 cm tall (rather than

9.5 cm, front walls)—now taller than the 18-cm postchange target. The priming block was covered with wood-patterned contact paper as in Experiment 1 (tall-block condition) or was additionally decorated with vertical yellow stripes (striped-block condition). Thus, the priming block differed from the target block only in height for the tall-block condition and in both height and pattern for the striped-block condition. If priming still arose when the priming and target blocks differed considerably, the infants should look longer at the change event than the no-change event. In contrast, if a high degree of similarity between priming and target blocks was necessary or if the infants in Experiment 1 were responding to the interaction violation rather than the height change, the infants in Experiment 2 should fail to notice the change and look about equally at the two events.

Unlike the occlusion condition of Experiment 1, the no-change and change events in Experiment 2 showed different objects at the beginning of the events and the same object at the end. In the no-change event, the 9-cm block was inserted into and withdrawn from the container; in the change event, the 18-cm block was inserted into the container and the 9-cm block was withdrawn from the container. Thus, we now compared infants' looking times at the same end state across two test events.



### Method

Thirty-two healthy-term infants aged 4.7 months to 5.8 months ($M_{age}$ = 5.1 months; 15 female, 17 male) participated. Infants were randomly assigned to one of two test-event orders (no change first, change first) in one of two conditions: tall-block ($M_{age}$ = 5.0 months) or striped-block ($M_{age}$ = 5.2 months). An additional 9 infants were excluded due to failing to complete both trials (3), distraction (3) or inattentiveness (1), or looking for the maximum time allowed on both trials (2).

The apparatus, stimuli, events, and procedure were identical to those in the occlusion condition of Experiment 1 (see Figure 4), except for the following differences. First, the priming block was 30 cm tall, 67% taller than the one used in Experiment 1. This change ensured that the priming block differed substantially in height from both the short and tall versions of the target (9 cm or 18 cm), allowing us to examine whether infants would still link the occlusion events to the containment event when the priming and target blocks differed in height. Second, in the striped-block condition, the priming block was decorated with vertical yellow stripes (1.6 cm wide). This additional difference allowed us to examine the extent to which the priming and target blocks can differ from each other while preserving priming. Third, a taller container (11 cm wide and 10 cm deep) was used: It was covered with blue contact paper with its edges trimmed with dark blue electrical tape. The front of the container was 19.5 cm tall, and to make it clear that it was a container, the back wall was 2 cm taller (21.5 cm). The taller container ensured that it could fully hide both the short and tall versions of the target and removed any interaction violations. If infants still responded differently to the change and no-change events, it could only be derived from their detection of the height change rather than the interaction violation. Finally, the same postchange target was withdrawn from the container at the end of both events to ensure that reported looking times were measured when infants looked at the identical paused scene.

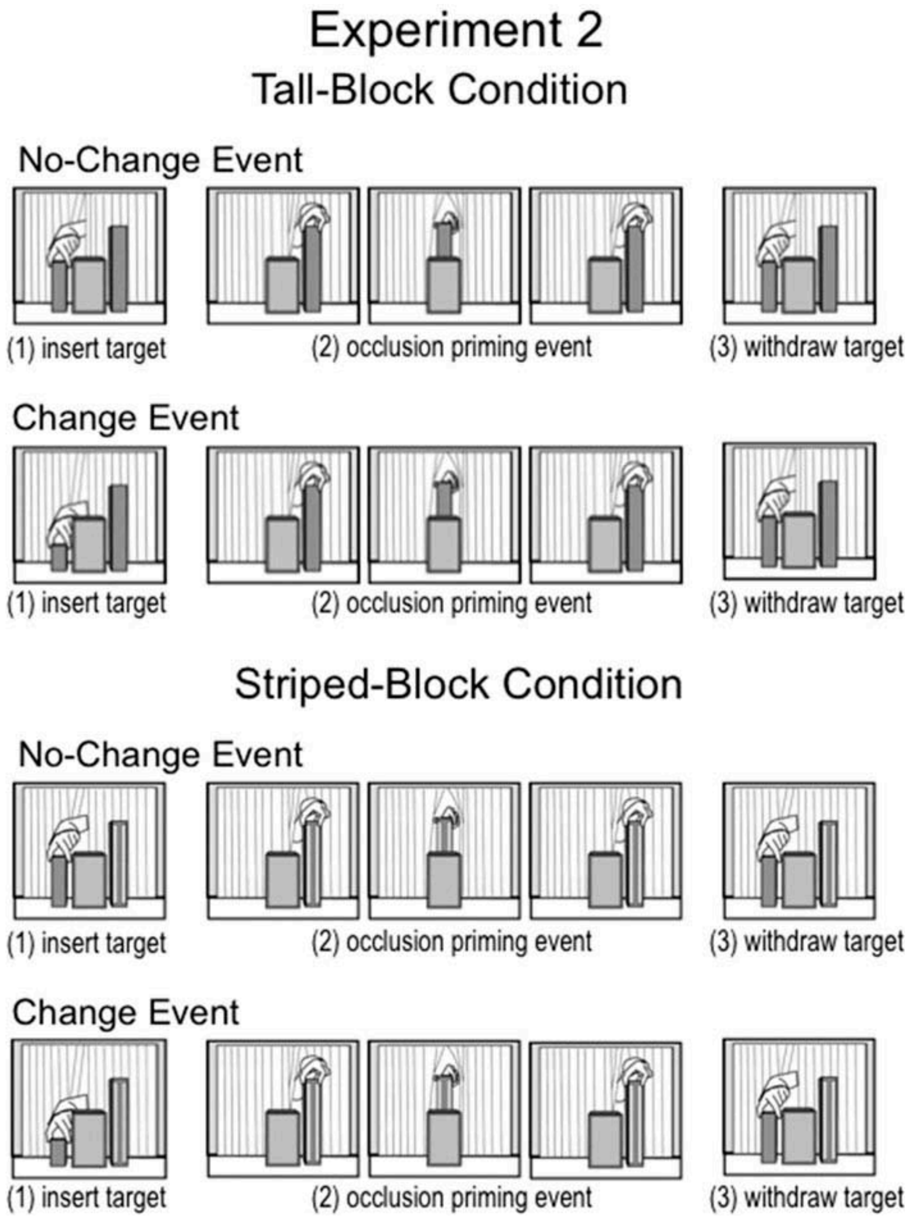


**Figure 4.** Schematic depiction of the no-change and change events in the tall- and striped-block conditions of Experiment 2.



### *Results and discussion*

Infants' looking times at the final paused scene of the change and no-change events (Figure 3) were compared by a 2 × 2 ANOVA, with condition (tall- or striped-block) as a between-subjects factor and event (change or no-change) as a within-subject factor. The analysis yielded a significant Condition × Event interaction, $F(1, 30) = 5.80$, $p = .022$, $\eta_p^2 = .16$. Planned contrasts indicated that infants in the tall-block condition looked significantly longer at the change event

($M = 13.3$ s, $SD = 6.8$ s) than the no-change event ($M = 9.9$ s, $SD = 5.0$ s), $F(1, 30) = 5.24$, $p = .029$, $d = 0.61$, whereas those in the striped-block condition looked about equally at the change event ($M = 10.5$ s, $SD = 6.1$ s) and the no-change event ($M = 12.2$ s, $SD = 5.8$ s), $F(1, 30) = 1.24$, $p = .274$, $d = 0.28$. Infants' individual responses were consistent with this pattern: Thirteen of 16 infants in the tall-block condition looked longer at the change event than the no-change event, $p < .05$ (binomial test, one-tailed), but only 5 of 16 in the striped-block condition did so, $p > .10$.

Next, we tested whether the priming events in the tall- and striped-block conditions were of similar interest to infants by comparing their total looking times during the 18-s priming portion of Segment 2. A 2 (condition) × 2 (event) ANOVA revealed no significant effects or interactions, $F$s < 1.91, $p$s > .17. Thus, the infants in both conditions appeared equally attentive to the priming segment, whether it involved a striped block or not and looked at the priming events for almost the entire duration (tall-block, $M = 17.2$ s, $SD = 1.0$ s; striped-block, $M = 17.3$ s, $SD = 1.6$ s).

In addition, we verified that infants' response to the change was comparable across the occlusion condition of Experiment 1 and the tall-block condition of Experiment 2—the two conditions in which the priming events included an occlusion component with priming blocks with the same texture/pattern as the target object. Infants' looking times in these two conditions were compared by a 2 (condition) × 2 (event) ANOVA. The main effect of event was significant, $F(1, 30) = 12.34$, $p = .001$, $\eta_p^2 = .21$, because infants looked longer at the change event ($M = 13.4$ s, $SD = 6.8$ s) than the no-change event ($M = 9.2$ s, $SD = 4.3$ s). Critically, the Condition × Event interaction was not significant, $F(1, 30) < 1$. The results were consistent with the claim that the change and no-change events were treated similarly across the two conditions in which infants saw occlusion events, whether the priming and target blocks were similar (occlusion condition) or different in height (tall-block condition) and whether there was an interaction violation (occlusion condition) or not (tall-block condition).

Finally, we compared the infants' looking times in the striped-block condition of Experiment 2 and the control condition of Experiment 1 using a 2 (condition) × 2 (event) ANOVA. The analysis did not yield any significant effects, all $p$s > .11, suggesting that infants' responses to the test events did not differ significantly across these two conditions—the infants in the striped-block condition looked about equally at the test events as did the infants in the control condition of Experiment 1, suggesting that neither priming event (non-occlusion with similar object; occlusion with dissimilar object) helped infants detect the height change.

In Experiment 2, the container was tall enough to fully hide both the prechange and postchange targets, and yet the 5-month-olds still noticed the change to the target's height when there was no interaction violation. In addition, the infants noticed the change when the priming block differed in height from both the prechange and postchange targets. By varying the level of similarity between the priming and target blocks, we also demonstrated one limitation of carryover. Specifically, we found no evidence of carryover when the priming and target blocks differed in both height and pattern. Thus, for 5-month-olds, the priming and target blocks need not be identical for carryover to occur, but a certain level of similarity seems to be necessary. The finding is consistent with the critical roles of similarity and comparison and provides a new example that perceptual similarity enhances children's processing of stimuli. Potentially, some level of similarity between the priming and target objects may enhance infants' ability to map the priming object to the target object and thus the priming event to the target event. This mapping could facilitate the carryover of information from the priming (occlusion) representations to the target (containment) representations. It is not clear, however, whether it was the combination of height and pattern differences or the pattern difference alone that mattered. Additionally, infants' processing limitations might explain why adding perceptual variation prevents carryover in general: The additional differences may increase processing demands beyond the capacity of these young infants. Future research could systematically manipulate the differences between the priming and target objects with different age groups to explore the conditions under which the physical-reasoning system will or will not retrieve information about the target.

## General discussion

Under many circumstances, infants' representations of physical events reflect unique characteristics of early physical knowledge: narrowly scoped and somewhat rigid. As shown in various tasks, infants may consider information about an object feature for some events but not for others (Baillargeon et al., 2012). However, information from one event category can be temporarily carried over to another to enhance processing of the second event. Priming demonstrates the remarkable flexibility in infants' representations of physical events and provides a useful test bed to elucidate the representational process in infancy. Here we specified the mechanism, carryover, underlying priming by teasing apart the encoding and retrieval mechanisms. The results support the idea that priming arises from enhanced retrieval. Although infants younger than 7.5 months old typically fail to detect interaction violations involving height in containment events (Hespos & Baillargeon, 2001, 2006), the 5-month-olds in the present experiments noticed the change to the target's height in a containment event after watching just a few repetitions of an occlusion event. Crucially, priming still occurred when the target became fully hidden before the occlusion priming events began. Given that the encoding of the prechange height could not be affected by the priming events, the results demonstrated that it was *retrieval*, not encoding, of information that was enhanced by the intervening priming events. This enhanced retrieval could have multiple sources, including direct facilitation of information retrieval or improved rehearsal or maintenance of the information; it is for future work to adjudicate between these possibilities.

Building on the systems account (e.g., Wang & Baillargeon, 2008b), our findings help clarify several aspects of the cognitive architecture underlying infants' representations of physical events. First, because the encoding of the target's height could not have been affected by the priming events in the present experiments, the object-representation system must be spontaneously encoding a range of object features. In the present case, the object-representation system spontaneously encoded at least height and shape information about the target. Second, because infants failed to detect the height change after watching the non-occlusion priming events, mere encoding of height information by the object-representation system does not guarantee the retrieval and use of information by the physical-reasoning system. Third, because watching the priming events enhanced infants' sensitivity to the change in containment events that involved object interaction, it is likely that the priming events affected how the physical-reasoning system retrieves information from the object-representation system.

Although the conditions were closely balanced for processing load (same objects, similar movements), infants' processing limits may still matter. For example, the lack of enhancement from the occlusion priming events using the striped block could stem from the increased demand of processing the additional striped feature in the priming object. In other words, when infants' representations of physical events are affected by carryover, as proposed by the systems account, processing demands may still play a role in limiting the carryover effects. Thus, although our results support the systems account, the impact of processing limits and contextual details (e.g., whether the object has stripes or not) cannot be ignored.

Although the priming events seemed to affect the retrieval, not encoding, of information about the height of the *prechange* object, it is logically possible that priming events may have influenced infants' encoding of the subsequent portion of the event—that is, infants' encoding of the height of the *postchange* object. The present results cannot rule out this possibility, but there is no clear reason to expect encoding to work differently for the prechange and postchange objects. Thus, for reasons of parsimony and in the absence of other data, we argue that the occlusion priming events enhance the retrieval of height information about the prechange and postchange objects. Future work can distinguish whether watching the priming events affects the retrieval of information about the *pre*change object, the *post*change object, or *both*. However, our findings clearly show that prechange object information is spontaneously encoded. Whether it will be retrieved and effectively used to notice a change depends on the types of priming events infants observe.

Priming has mostly been observed during the second half of infants' 1st year in physical-reasoning tasks that require infants to detect interaction violations (Baillargeon et al., 2012; Wang & Baillargeon, 2005; Wilcox & Woods, 2009; Wilcox et al., 2008). Similar facilitation effects have also been observed in tasks that require infants to remember simple patterns, categorically related items, or a previously learned behavior (e.g., Bearce & Rovee-Collier, 2006; Fagan, 1974; Oakes & Kovack-Lesh, 2013). Facilitation effects are typically weak in infants younger than 6 months old or when transfer across different contexts is required (e.g., Borovsky & Rovee-Collier, 1990; Oakes, Kovack-Lesh, & Horst, 2009; Wang & Kohne, 2007). Here we showed that infants at 5 months could be induced to retrieve key information in a task that involved two different spatial contexts, thus extending evidence for priming to earlier months of life and to situations where the task is to remember object features and detect a change.

Our results also indicated that infants at 5 months old are capable of maintaining height information for at least 20 s, suggesting a robust memory for object features at this young age. Shifting from one context (occlusion) to another (containment) did not interrupt infants' memory for object height—a sharp contrast with infants' limitations in previous tasks (e.g., Borovsky & Rovee-Collier, 1990). Previous memory tasks have required infants to remember an association between their action and its effect, whereas our task required infants to remember an object feature for later recognition. It could be that our task required less action planning and execution, thus resulting in better transfer across different contexts.

In previous work, facilitation dissipated when the priming and target events were separated by a 20-s gap (Wang, 2011). Specifically, 4.5-month-olds detected an interaction violation involving height in containment events after an 8-s delay but not a 20-s delay, suggesting that facilitation dissipates over time. The present experiments took one step further to show the source of the apparent dissipation. In the present experiments, facilitation occurred when the gap between the priming event and the retrieval of information lasted about 4 s (1 s to return the priming block to its initial position, at least 2 s of looking at the static display, and 1 s to withdraw the postchange target). Thus, the failure after a 20-s delay shown in Wang (2011) was probably not due to a loss of height information in memory, as the present experiments showed that infants are capable of maintaining height information after a 20-s delay. Instead, the problem was likely a failure to appropriately retrieve the information. Moreover, infants' success in retrieving the information appeared to hinge on temporal proximity between the priming and target events.

To conclude, the present findings provide evidence that is consistent with the systems account and further suggest that separate encoding and retrieval systems may underlie infants' representations of physical events. When infants watch a series of events, their ability to effectively use object information can be primed through improved retrieval (not encoding) of information by the physical-reasoning system. Thus, for infants, as for adults (e.g., Mitroff et al., 2004), apparent failure in a task does not mean that relevant information has not been encoded or maintained over time. Rather, appropriate retrieval of information plays a crucial role and is influenced by current knowledge and intervening events between encoding and retrieval. The present findings clarify fine-grained aspects of the representational process and demonstrate that, despite processing limits, young infants are capable of expanding their use of information for a physical event through brief observation of other events.

## Acknowledgments

We thank Marta Gunin for discussion and the families who kindly participated in the research.

## Funding

This research was supported by a Special Research Grant awarded by the Committee on Research from the University of California–Santa Cruz to SW and grants from the Natural Sciences and Engineering Research Council of Canada and the Social Sciences and Humanities Research Council of Canada to KO.

## References

Baillargeon, R., & DeVos, J. (1991). Object permanence in young infants: Further evidence. *Child Development*, *62*, 1227–1246. doi:10.2307/1130803

Baillargeon, R., Li, J., Gertner, Y., & Wu, D. (2011). How do infants reason about physical events? In U. Goswami (Ed.), *The Wiley-Blackwell handbook of childhood cognitive development* (2nd ed., pp. 11–48). Oxford, England: Blackwell.

Baillargeon, R., Li, J., Ng, W., & Yuan, S. (2009). A new account of infants' physical reasoning. In A. Woodward & A. Needham (Eds.), *Learning and the infant mind* (pp. 66–116). New York, NY: Oxford University Press.

Baillargeon, R., Stavans, M., Wu, D., Gertner, Y., Setoh, P., Kittredge, A. K., & Bernard, A. (2012). Object individuation and physical reasoning in infancy: An integrative account. *Language Learning and Development*, *8*, 4–46. doi:10.1080/15475441.2012.630610

Bearce, K. H., & Rovee-Collier, C. (2006). Repeated priming increases memory accessibility in infants. *Journal of Experimental Child Psychology*, *93*, 357–376. doi:10.1016/j.jecp.2005.10.002

Borovsky, D., & Rovee-Collier, C. (1990). Contextual constraints on memory retrieval at 6 months. *Child Development*, *61*, 1569–1583. doi:10.1111/j.1467-8624.1990.tb02884.x

Carey, S., & Xu, F. (2001). Infants' knowledge of objects: Beyond object files and object tracking. *Cognition*, *80*, 179–213. doi:10.1016/S0010-0277(00)00154-2

Casasola, M., & Cohen, L. (2002). Infants' categorization of containment, support and tight-fit spatial relationships. *Developmental Science*, *5*, 247–264. doi:10.1111/1467-7687.00226

Casasola, M., Cohen, L. B., & Chiarello, E. (2003). Six-month-old infants' categorization of containment spatial relations. *Child Development*, *74*, 679–693. doi:10.1111/1467-8624.00562

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*, *82*, 407–428. doi:10.1037/0033-295X.82.6.407

Duffy, S., Huttenlocher, J., LeVine, S., & Duffy, R. (2005). How infants encode spatial extent. *Infancy*, *8*, 81–90. doi:10.1207/s15327078in0801_5

Duh, S., & Wang, S. (2014). Infants detect changes in everyday scenes: The role of scene gist. *Cognitive Psychology*, *72*, 142–161. doi:10.1016/j.cogpsych.2014.03.001

Fagan, J. F. (1974). Facilitation of infants' recognition memory. *Child Development*, *49*, 1066–1075. doi:10.1111/j.1467-8624.1978.tb04075.x

Ferry, A. L., Hespos, S. J., & Gentner, D. (2015). Prelingistic relational concepts: Investigating analogical processing in infants. *Child Development*, *86*, 1386–1405. doi:10.1111/cdev.12381

Gentner, D., Anggoro, F. K., & Klibanoff, R. S. (2011). Structure mapping and relational language support children's learning of relational categories. *Child Development*, *82*, 1173–1188. doi:10.1111/j.1467-8624.2011.01599.x

Gentner, D., Loewenstein, J., & Hung, B. (2007). Comparison facilitates children's learning of names for parts. *Journal of Cognition and Development*, *8*, 285–307. doi:10.1080/15248370701446434

Gentner, D., & Medina, J. (1998). Similarity and the development of rules. *Cognition*, *65*, 263–297. doi:10.1016/s0010-0277(98)00002-x

Gopnik, A. (2012). Scientific thinking in young children: Theoretical advances, empirical research, and policy implications. *Science*, *337*, 1623–1627. doi:10.1126/science.1223416

Gopnik, A., Griffiths, T. L., & Lucas, C. G. (2015). When younger learners can be better (or at least more open-minded) than older ones. *Current Directions in Psychological Science*, *24*, 87–92. doi:10.1177/0963721414556653

Hespos, S. J., & Baillargeon, R. (2001). Infants' knowledge about occlusion and containment events: A surprising discrepancy. *Psychological Science*, *12*, 140–147. doi:10.1111/1467-9280.00324

Hespos, S. J., & Baillargeon, R. (2006). Décalage in infants' knowledge about occlusion and containment events: Converging evidence from action tasks. *Cognition*, *99*, B31–B41. doi:10.1016/j.cognition.2005.01.010

Hollingworth, A. (2003). Failures of retrieval and comparison constrain change detection in natural scenes. *Journal of Experimental Psychology: Human Perception and Performance*, *29*, 388–403. doi:10.1037/0096-1523.29.2.388

Huttenlocher, J., Duffy, S., & Levine, S. C. (2002). Infants and toddlers discriminate amount: Are they measuring? *Psychological Science*, *13*, 244–249. doi:10.1111/1467-9280.00445

Kwon, M., Luck, S. J., & Oakes, L. M. (2014). Visual short-term memory for complex objects in 6- and 8-month-old infants. *Child Development*, *85*, 564–577. doi:10.1111/cdev.12161

Leslie, A. M. (2004). Who's for learning? *Developmental Science*, *7*, 417–419. doi:10.1111/j.1467-7687.2004.00359.x

Luo, Y., Kaufman, L., & Baillargeon, R. (2009). Young infants' reasoning about physical events involving inert and self-propelled objects. *Cognitive Psychology*, *58*, 441–486. doi:10.1016/j.cogpsych.2008.11.001

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, *90*, 227–234. doi:10.1037/h0031564

Mitroff, S. R., Simons, D. J., & Levin, D. T. (2004). Nothing compares 2 views: Change blindness results from failures to compare retained information. *Perception & Psychophysics*, *66*, 1268–1281. doi:10.3758/bf03194997

Needham, A. (1998). Infants' use of featural information in the segregation of stationary objects. *Infant Behavior & Development*, *21*, 47–75. doi:10.1016/S0163-6383(98)90054-6

Needham, A. (1999). The role of shape in 4-month-old infants' segregation of adjacent objects. *Infant Behavior & Development*, *22*, 161–178. doi:10.1016/s0163-6383(99)00008-9

Oakes, L. M., & Kovack-Lesh, K. A. (2013). Infants' visual recognition memory for a series of categorically related items. *Journal of Cognition and Development*, *14*, 63–86. doi:10.1080/15248372.2011.645971

Oakes, L. M., Kovack-Lesh, K. A., & Horst, J. S. (2009). Two are better than one: Comparison influences infants' visual recognition memory. *Journal of Experimental Child Psychology*, *104*, 124–131. doi:10.1016/j.jecp.2008.09.001

Rigney, J., & Wang, S. (2015). Delineating the boundaries of infants' spatial categories: The case of containment. *Journal of Cognition & Development*, *16*, 420–441. doi:10.1080/15248372.2013.848868

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2004). Infant visual recognition memory. *Developmental Review*, *24*, 74–100. doi:10.1016/j.dr.2003.09.004

Ross-Sheehy, S., Oakes, L. M., & Luck, S. J. (2003). The development of visual short-term memory capacity in infants. *Child Development*, *74*, 1807–1822. doi:10.1046/j.1467-8624.2003.00639.x

Rovee-Collier, C., & Cuevas, K. (2009). Multiple memory systems are unnecessary to account for infant memory development: An ecological model. *Developmental Psychology*, *45*, 160–174. doi:10.1037/a0014538

Sitskoorn, S. M., & Smitsman, A. W. (1995). Infants' perception of dynamic relations between objects: Passing through or support? *Developmental Psychology*, *31*, 437–447. doi:10.1037/0012-1649.31.3.437

Wang, S. (2011). Priming 4.5-month-old infants to use height information by enhancing retrieval. *Developmental Psychology*, *47*, 26–38. doi:10.1037/a0021060

Wang, S., & Baillargeon, R. (2005). Inducing infants to detect a physical violation in a single trial. *Psychological Science*, *16*, 542–549. doi:10.1111/j.0956-7976.2005.01572.x

Wang, S., & Baillargeon, R. (2006). Infants' physical knowledge affects their change detection. *Developmental Science*, *9*, 173–181. doi:10.1111/j.1467-7687.2006.00477.x

Wang, S., & Baillargeon, R. (2008a). Can infants be 'taught' to attend to a new physical variable in an event category? The case of height in covering events. *Cognitive Psychology*, *56*, 284–326. doi:10.1016/j.cogpsych.2007.06.003

Wang, S., & Baillargeon, R. (2008b). Detecting impossible changes in infancy: A three-system account. *Trends in Cognitive Sciences*, *12*, 17–23. doi:10.1016/j.tics.2007.10.012

Wang, S., & Kohne, L. (2007). Visual experience enhances 9-month-old infants' use of task-relevant information in an action task. *Developmental Psychology*, *43*, 1513–1522. doi:10.1037/0012-1649.43.6.1513

Wang, S., & Mitroff, S. R. (2009). Preserved visual representations despite change blindness in infants. *Developmental Science*, *12*, 681–687. doi:10.1111/j.1467-7687.2008.00800.x

Wang, S., Zhang, Y., & Baillargeon, R. (2016). Young infants view physically possible support events as unexpected: New evidence for rule learning. *Cognition*, *157*, 100–105. doi:10.1016/j.cognition.2016.08.021

Wilcox, T. (1999). Object individuation: Infants' use of shape, size, pattern, and color. *Cognition*, *72*, 125–166. doi:10.1016/S0010-0277(99)00035-9

Wilcox, T., & Chapa, C. (2004). Priming infants to attend to color and pattern information in an individuation task. *Cognition*, *90*, 265–302. doi:10.1016/S0010-0277(03)00147-1

Wilcox, T., & Woods, R. (2009). Experience primes infants to individuate objects: Illuminating learning mechanisms. In A. Needham & A. Woodward (Eds.), *Learning and the infant mind* (pp. 117–143). New York, NY: Oxford University Press.

Wilcox, T., Woods, R., & Chapa, C. (2008). Color-function categories that prime infants to use color information in an object individuation task. *Cognitive Psychology*, *57*, 220–261. doi:10.1016/j.cogpsych.2208.02.001