Developmental Science 9:2 (2006), pp 173–181

REPORT

Infants' physical knowledge affects their change detection

Su-hua Wang[1] and Renée Baillargeon[2]

1. *Department of Psychology, University of California, Santa Cruz, USA*
2. *Department of Psychology, University of Illinois at Urbana-Champaign, USA*

Abstract

Prior research suggests that infants attend to a variable in an event category when they have identified it as relevant for predicting outcomes in the category, and that the age at which infants identify a variable depends largely on the age at which they are exposed to appropriate observations. Thus, depending on age of exposure, infants may identify the same variable at different ages in different event categories. A good case in point is the variable height, which is identified at about 3.5 months in occlusion events, but only at about 12 months in covering events and 14 months in tube events. In the present experiments, 11-month-olds detected a change to an object's height in an occlusion but not a covering event, and 12.5-month-olds detected a similar change in a covering but not a tube event. Thus, infants succeeded in detecting a change to an object's height in an event where height had been identified as a relevant variable, but failed to detect the exact same change in another event where height had not yet been identified as a relevant variable. These findings provide evidence that infants' physical knowledge affects which changes they detect in physical events. Possible mechanisms underlying these findings are also discussed, in light of recent accounts of change detection in adults.

Introduction

Developmental researchers have long been interested in specifying the nature and contents of infants' mental representations. In particular, how rich or sparse are infants' representations of physical events? How much information is initially included in these representations, and how does it increase with age and experience? One method of choice for addressing these questions over the past 30 years has been to study infants' ability to detect changes to objects that are briefly hidden (e.g. Bower, 1974; Goldberg, 1976; LeCompte & Gratch, 1972; Meicler & Gratch, 1980; Muller & Aslin, 1978; Newcombe, Huttenlocher & Learmonth, 1999; Simon, Hespos & Rochat, 1995; Wilcox, 1999). In these experiments, an object is hidden behind a screen, under a cloth, or in sand, and then a different object is revealed; evidence that infants detect the change suggests that they represent sufficient information about the first object to distinguish it from the second object. To illustrate, Wilcox (1999) showed infants events in which a first object disappeared behind a screen; after a brief pause, a second object that differed in size, shape, pattern or color from the first object reappeared from behind the screen (the screen was too narrow to hide both objects at once). Infants detected size and shape changes at about 4.5 months, pattern changes at about 7.5 months and color changes at about 11.5 months. Thus, 4.5-month-olds were surprised when a large ball disappeared behind a screen and a small ball reappeared from behind it; however, they were not surprised when a green ball disappeared behind a screen and a red ball reappeared from behind it.

Why did the infants in Wilcox's (1999) experiments succeed in detecting some but not all of the changes they were shown? A recent account (e.g. Baillargeon, 2004; Wang, Baillargeon & Paterson, 2005) suggests that infants' *physical knowledge* determines what information they include in their representations of events, and hence what surreptitious changes (and other violations) they can detect in the events. In the next sections, we briefly describe this account and then introduce the present research, which sought further evidence that infants' physical knowledge affects their ability to detect surreptitious changes to objects.

An account of infants' physical reasoning

According to recent research on the development of infants' physical knowledge, infants 'sort' events into

Address for correspondence: Su-hua Wang, Department of Psychology, University of California, 1156 High Street, Santa Cruz, CA 95064, USA; e-mail: suhua@ucsc.edu

distinct categories; many of these *event categories* capture simple spatial relations between objects, such as 'object behind nearer object, or occluder' (occlusion events), 'object inside container' (containment events) and 'object under cover' (covering events) (e.g. Baillargeon & Wang, 2002; Casasola, Cohen & Chiarello, 2003; Hespos & Baillargeon, in press; McDonough, Choi & Mandler, 2003; Wang *et al.*, 2005; Wilcox & Chapa, 2002). In each event category, infants gradually identify the *variables* (e.g. size, shape, pattern or color information) that are relevant for predicting outcomes (e.g. Baillargeon & DeVos, 1991; Hespos & Baillargeon, 2001; McCall, 2001; Sitskoorn & Smitsman, 1995; Wang, Baillargeon & Brueckner, 2004; Wang *et al.*, 2005).

Infants' knowledge of the variables relevant to each event category affects what information they attend to and represent when reasoning about events from the category (e.g. Baillargeon, 2004; Wang *et al.*, 2005). When watching an event, infants build a specialized *physical representation* of the event that is used to predict and interpret its outcome. To start, infants represent the basic spatiotemporal information about the event, and use this information to categorize it. Infants then access their knowledge of the category selected; this knowledge specifies the variables that have been identified as relevant for predicting outcomes in the category. Information about identified variables is included in the representation; information about unidentified variables is not (unless infants are primed or otherwise induced to do so; e.g. Wang & Baillargeon, 2005b; Wilcox & Chapa, 2004). Both the basic and the variable information included in the representation become subject to a few core principles (e.g. Leslie, 1994; Spelke, 1994), such as that of continuity: objects exist continuously in time and space, retaining their physical properties as they do so (e.g. Baillargeon, Li, Luo & Wang, in press).

The preceding account helps make clear how infants' physical knowledge – and more specifically their knowledge of the variables that are relevant for predicting outcomes in each event category – might affect their ability to detect surreptitious changes to objects. Because at 4.5 months infants have identified size and shape but not pattern and color as occlusion variables (e.g. Baillargeon & DeVos, 1991; Hespos & Baillargeon, 2001; Needham, 1998; Wang *et al.*, 2004), they include only size and shape information in their physical representations of occlusion events. As a result, they can detect size and shape changes in these events, but not color and pattern changes (Wilcox, 1999). Infants who do not include information about the color of a ball in their representation of an occlusion event are unlikely to notice when the ball changes from green to red behind the occluder.

Event category effects

The findings discussed above suggest that whether infants detect changes involving different variables within an event category depends on whether they have identified each of the variables as relevant to the category. But what of infants' ability to detect changes involving the *same* variable in *different* event categories? For example, would infants who detected a change to the height of an object that became hidden behind an occluder detect the very same change if the object became hidden under a cover or inside a tube? Recent findings, reviewed below in three points, suggest that the answer to this question may be negative.

First, when infants identify a variable as relevant to an event category, they do not generalize this variable to other categories: they learn separately about each category (e.g. Hespos & Baillargeon, 2001; Wang *et al.*, 2005). Second, the age at which infants identify a variable in any event category depends largely on the age at which they are exposed to appropriate observations from which to abstract the variable; for example, in order to identify the variable height in covering events, infants must first notice that tall objects extend below short but not tall covers (e.g. Baillargeon, 2002; Wang & Baillargeon, 2005a). Third, because the age of exposure to appropriate observations for a variable can differ substantially across event categories, the same variable can be identified at very different ages in different categories. Thus, although the variable height is identified at about 3.5 months in occlusion events (infants are surprised when a tall object becomes fully hidden behind a short occluder; Baillargeon & DeVos, 1991), it is not identified until about 7.5 months in containment events (Hespos & Baillargeon, 2001, in press), 12 months in covering events (McCall, 2001; Wang *et al.*, 2005) and 14 months in tube events (Wang *et al.*, 2005).

The preceding results suggest that infants who detect a change to an object's height in one event where height has been identified as a relevant variable may fail to detect the very same change in another event where height has not yet been identified as a relevant variable. The present research tested this prediction. Experiment 1 examined 11-month-olds' ability to detect a height change in an occlusion and a covering event, and Experiment 2 examined 12.5-month-olds' ability to detect a height change in a covering and a tube event.

We reasoned that findings consistent with our predictions would be important for several reasons. First, such results would provide new evidence that infants' physical knowledge affects their ability to detect surreptitious changes to objects. Second, the results would provide additional support for the account of infants' physical reasoning described above and more generally for the notion that what changes infants detect depends at least in part on what information they include in their physical representations of events. Finally, the results would raise interesting questions about possible relations between infants' and adults' failures to detect changes. Like infants, adults sometimes fail to detect large changes to objects or scenes that are briefly hidden (for recent reviews, see Hollingworth & Henderson, 2002; Rensink, 2002; Simons, 2000; Simons & Rensink, 2005). For example, in a classic series of experiments (Simons & Levin, 1998), an experimenter holding a map approached a pedestrian on a college campus and asked for directions. In the course of their interaction, experimental assistants carried a large door between them. During this brief interruption, the experimenter and one of the assistants surreptitiously switched places. The assistant then continued the interaction with the pedestrian. About half of the pedestrians tested failed to notice the change in the experimenter and were surprised to learn that the person before them was not the one who had initiated the conversation. In recent years, several mechanisms have been invoked to explain these and related 'change blindness' results in adults (for recent reviews, see Mitroff, Simons & Levin, 2004; Simons & Ambinder, 2005; Simons & Rensink, 2005); in the General Discussion, we ask whether the same or different mechanisms might underlie infants' failures to detect surreptitious changes to objects.

Experiment 1

Experiment 1 examined 11-month-old infants' ability to detect a change to the height of an object; this change took place while the object was briefly hidden *behind* (occlusion condition) or *under* (covering condition) a cover. The infants in each condition received a single test trial in which they saw a no-change or a change event (Figure 1). At the start of each event, a tall cover stood next to a short object on an apparatus floor; the object was less than half as tall as the cover. After the infant had looked at the scene for two cumulative seconds, an experimenter introduced his/her right gloved hand into the apparatus. The hand grasped the cover and then rotated it 90 degrees upward to show its hollow interior. After the infant had looked for another two cumulative seconds, the hand returned the cover to its starting position. Next, the hand lifted the cover and lowered it in front of (occlusion condition) or over (covering condition) the object, in either case fully hiding it. After a few seconds, the hand returned the cover to its starting position and then paused; the infants saw this final paused scene until the trial ended (see below). In the no-change event, when the cover was removed, the object was the same as before; in the change event, the object was now about as tall as the cover.

At 11 months of age, infants have identified height as an occlusion but not a covering variable: they are surprised when a tall object becomes fully hidden behind a short occluder, but not under a short cover (e.g. Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987; Hespos & Baillargeon, 2001, in press; McCall, 2001; Wang *et al.*, 2005). Therefore, we expected that the infants in the occlusion but not the covering condition would include height information in their physical representations of the test events, and hence that only the infants in the occlusion condition would detect the surreptitious change to the object's height in the change event. Different looking patterns were thus predicted for the two conditions.

Method

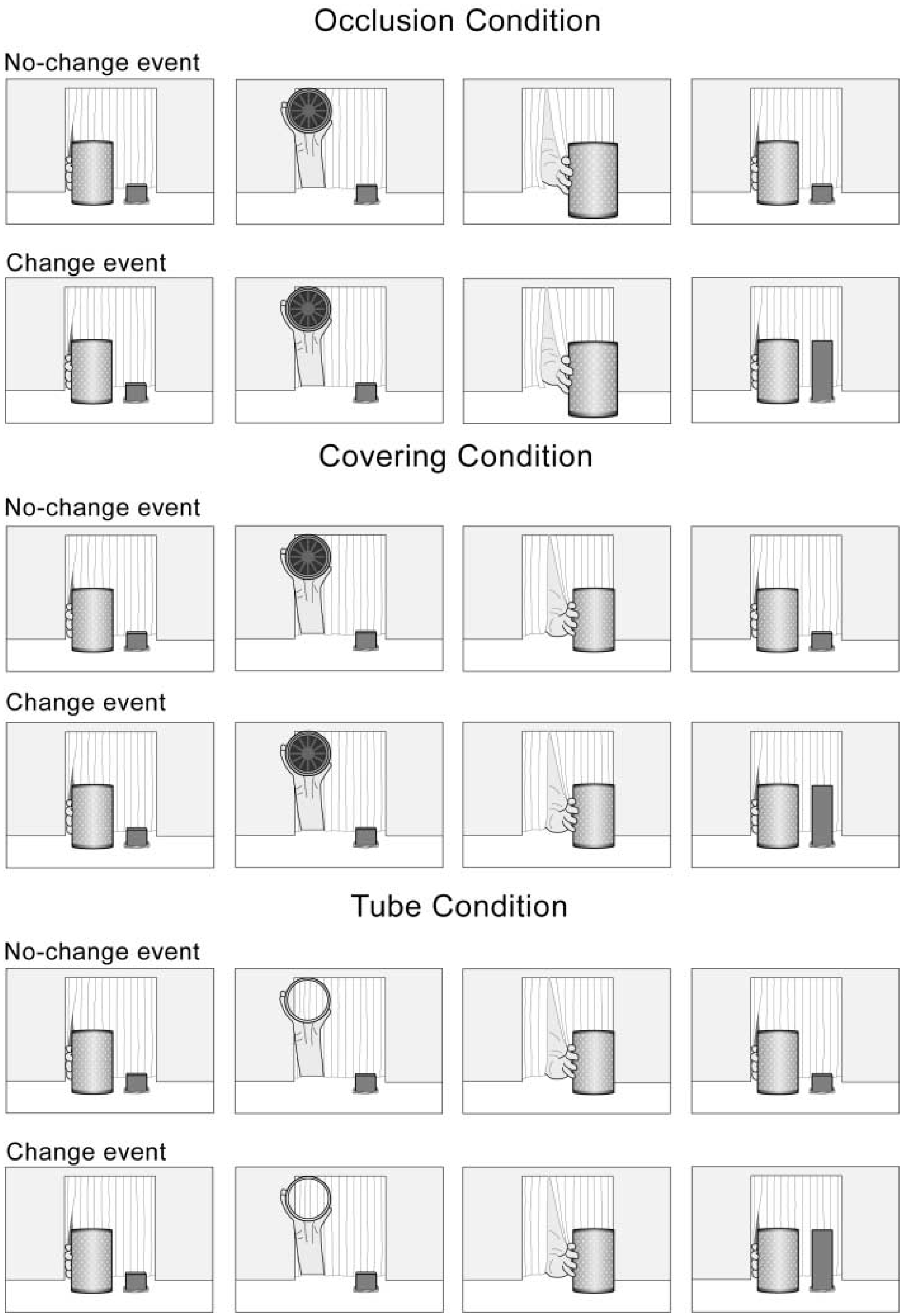
Participants

Participants were 32 healthy term infants, 17 male and 15 female (M = 11 months, 5 days; range = 10 months, 2 days to 11 months, 24 days). An additional four infants were eliminated because of fussiness (1), distraction (1), or observer difficulties (2). Half of the infants were randomly assigned to the occlusion condition (M = 11 months, 5 days), and half to the covering condition (M = 11 months, 5 days). Within each condition, half of the infants saw the change event, and half the no-change event.

Apparatus

The apparatus consisted of a wooden display booth (106 cm high × 103.5 cm wide × 60 cm deep) that was mounted 76 cm above the room floor. The floor and back wall of the apparatus were covered with pastel contact paper and the side walls were painted white. In the front wall was a large opening (44.5 cm × 97 cm); between trials, a wooden frame (72.5 cm × 101 cm) covered with white fabric was lowered in front of this opening. The back wall had a window (33 cm × 23.5 cm) extending from its lower edge; the window was located 41.5 cm from the left wall and was filled with a white fringe. An experimenter introduced his or her right hand (in a yellow rubber glove) into the apparatus through the window.

The cover (11.5 cm in diameter × 16.5 cm tall) was light blue with a small white pattern; its interior was white with thin red stripes. The object was a red rectangular box (5.5 cm wide × 5.75 cm deep) that protruded through a hole (5.8 cm wide × 6.5 cm deep) in the


Occlusion Condition
No-change event
Change event
Covering Condition
No-change event
Change event
Tube Condition
No-change event
Change event

apparatus floor. The object was attached under the floor to a platform that could be lifted to extend the portion of the object visible above the floor. The object was 4.5 cm tall at the beginning of each test trial, and was either 4.5 cm tall (no-change event) or 15.5 cm tall (change event) at the end of the trial. Around the bottom of the object was a yellow and orange pipe cleaner (0.5 cm in diameter) that concealed the small gap between the object and the hole in the apparatus floor.

At the start of each trial, the cover stood 42 cm from the left wall and 18.5 cm from the back wall of the apparatus; the object stood centered 2.5 cm to the right of the cover. Each infant sat on a parent's lap facing the opening in the front wall of the apparatus, centered in front of the object.

Procedure

During the test trial, the infants saw either a no-change or a change event. At the beginning of the trial, a hand lowered a tall cover in front of (occlusion condition) or over (covering condition) a short object, returned the cover to its starting position on the apparatus floor, and paused (pre-trial); the infants then watched this paused scene until the trial ended (main-trial). When revealed, the object was either the same as before (no-change event) or much taller than before (change event). Looking times during the pre-trial and main-trial were computed separately. The main-trial ended when the infants looked away from the paused scene for 2 consecutive seconds after having looked at it for at least 3 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 looking times determined when a trial ended. Inter-observer agreement in this and the following experiment averaged 94% per trial per infant.

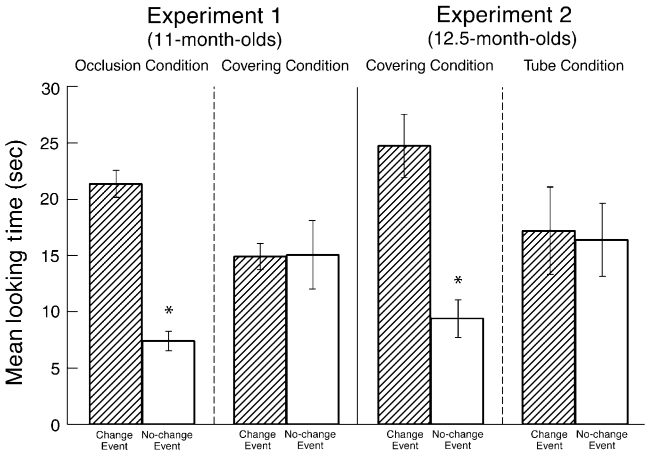


Figure 2 *Mean looking times of the infants in Experiments 1 and 2 at the change and no-change test events. Error bars represent standard errors.*

Preliminary analyses in this and the next experiment revealed no significant interaction among condition, event and sex; the data were thus collapsed across sex in subsequent analyses.

Results and discussion

The infants' looking times during the main-trial portion of the test trial (Figure 2) were analyzed by a 2 × 2 analysis of variance (ANOVA) with condition (occlusion or covering) and event (change or no-change) as between-subjects factors. The analysis revealed a significant main effect of event, $F(1, 28) = 5.57$, $p < .05$, and a significant condition × event interaction, $F(1, 28) = 5.81$, $p < .025$. Planned comparisons indicated that, in the occlusion condition, the infants who saw the change event (M = 21.4) looked reliably longer than those who saw the

Figure 1 *Test events in the occlusion and covering conditions of Experiment 1 and in the covering and tube conditions of Experiment 2.* Occlusion condition. *At the start of each event, the cover stood next to the object. After the infant had looked at this scene for two cumulative seconds, a gloved hand entered the apparatus and grasped the cover (2 s). The hand then rotated the cover 90 degrees upward to show its hollow interior (2 s). After the infant had looked for another two cumulative seconds, the hand returned the cover to its starting position (2 s). Next, the hand lifted the cover (1 s) and moved it toward the infant (1 s) and to the right (1 s) until it stood centered about 2.5 cm above and 2.5 cm in front of the object. The hand lowered the cover to the apparatus floor in front of the object (2 s), and then released the cover and paused next to it (2 s). Finally, the hand grasped the cover (2 s), lifted it (2 s), moved it to the left (1 s) and back (1 s), lowered it to its starting position on the apparatus floor (1 s), and paused. The infants watched this final paused scene until the trial ended. When revealed, the object was either as tall (no-change event) or over twice as tall (change event) as before.* Covering condition. *The events shown in the covering condition were similar to those in the occlusion condition, with the following exceptions. After rotating the cover and returning it to the apparatus floor, the hand lifted the cover (2 s), and moved it directly to the right (1 s) until it stood centered about 2.5 cm above the object. The hand lowered the cover over the object (2 s), and then released it and paused (2 s). Next, the hand grasped the cover (2 s), lifted it (2 s), moved it to the left (1 s), and lowered it to its starting position on the apparatus floor (2 s).* Tube condition. *The events shown in the tube condition were similar to those in the covering condition except that the cover was replaced by a tube identical to the cover with its top removed.*

no-change event (M = 7.4), $F(1, 28) = 11.37$, $p < .005$, Cohen's d = 1.97; in the covering condition, in contrast, the infants who saw the change (M = 14.9) and no-change (M = 15.0) events looked about equally, $F(1, 28) = 0.00$, Cohen's d = 0.02. Wilcoxon Rank-Sum tests confirmed these results (occlusion: $W_s = 41$, $p < .005$; covering: $W_s = 66$, $p > .10$).

The infants in the occlusion condition who saw the change event looked reliably longer than those who saw the no-change event. In contrast, the infants in the covering condition looked about equally at the two events. The infants thus detected the change to the height of the object when it took place in the context of an occlusion event, but failed to detect the very same change when it took place in the context of a covering event.

The results of Experiment 1 provide clear evidence that infants' ability to detect a surreptitious change involving a variable in different event categories depends on whether they have identified the variable as relevant to each category. Infants who have identified a variable in one category but not another are likely to detect a change involving the variable only in the first category – even when the change effected is exactly the same in the two categories. Experiment 2 sought further evidence for these conclusions.

Experiment 2

At 12 months of age, infants are surprised when a tall object becomes fully hidden under a short cover, but not inside a short tube; it is not until infants are about 14 months that they detect this last violation (e.g. McCall, 2001; Wang *et al.*, 2005). These findings suggest that 12-month-olds have identified the variable height as relevant to covering but not tube events. Thus, infants of this age should succeed in detecting a surreptitious change to the height of an object when this change takes place in the context of a covering but not a tube event. Experiment 2 examined this prediction with 12.5-month-olds.

The infants were assigned to a covering or a tube condition. The infants in the covering condition saw the same change and no-change events as in the covering condition of Experiment 1. Those in the tube condition saw identical events, except that the top of the cover was removed to create a tube. At the start of the change or no-change event, when the experimenter rotated the tube 90 degrees upward to show its interior, the infants could see that the tube was open at both ends (Figure 1). The hand next lowered the tube over the object, and then returned it to the apparatus floor. As in the covering condition, the object, when revealed, was either the same height as before (no-change event) or much taller than before (change event).

Because at 12.5 months infants have identified height as a covering but not a tube variable, we expected that the infants in the covering but not the tube condition would include height information in their physical representations of the test events, and hence that only the infants in the covering condition would detect the surreptitious change to the object's height in the change event. As in Experiment 1, different looking patterns were thus predicted for the two conditions.

Method

Participants

Participants were 32 healthy term infants, 16 male and 16 female (range = 11 months, 25 days to 13 months, 13 days; M = 12 months, 18 days). Another two infants were eliminated, one because she was fussy and one because he stood up and might have seen the object change height inside the tube. Half of the infants were assigned to the covering condition (M = 12 months, 15 days), and half to the tube condition (M = 12 months, 20 days). In each condition, half of the infants saw the change event, and half the no-change event.

Procedure

The procedure was the same as in Experiment 1 with only one modification: in the tube condition, a tube was used that was identical to the cover with its top removed. Because the tube was taller than the tall object, the infants (as long as they remained seated) could not see the object change height inside the tube in the change event.

Results and discussion

The infants' looking times during the main-trial portion of the test trial (Figure 2) were analyzed as in Experiment 1. The analysis revealed a significant main effect of event, $F(1, 28) = 5.35$ $p < .05$, and a significant condition × event interaction, $F(1, 28) = 4.35$, $p < .05$. Planned comparisons indicated that, in the covering condition, the infants who saw the change event (M = 24.7) looked reliably longer than those who saw the no-change event (M = 9.3), $F(1, 28) = 9.68$, $p < .005$, Cohen's d = 1.76; in the tube condition, in contrast, the infants who saw the change (M = 17.2) and no-change (M = 16.4) events looked about equally, $F(1, 28) = 0.03$, Cohen's d = 0.07. Wilcoxon Rank-Sum tests confirmed these results (covering: $W_s = 41$, $p < .005$; tube: $W_s = 66$, $p > .10$).

Although the 12.5-month-olds in Experiment 2 had no difficulty detecting the change to the object's height in the covering condition, they appeared blind to this same change in the tube condition. These results provide additional evidence that infants' physical knowledge affects their ability to detect changes. Infants who have identified a variable in one event category but not another are likely to detect a change involving the variable only in the first category. Furthermore, this is true even when the same change occurs in the two categories, and when the events from the two categories are perceptually highly similar. In Experiment 2, the hand performed exactly the same actions in the covering and tube conditions; the only difference between the two conditions was whether a cover or a tube (identical except for their top) was lowered over the object. Despite this marked similarity, the infants detected the change only in the covering condition.

Further analysis

The responses of the infants in the *covering* condition of Experiments 1 and 2 were compared in a 2×2 ANOVA with age (11- or 12.5-month-olds) and event (change or no-change) as between-subjects factors. The analysis revealed a significant main effect of event, $F(1, 28) = 5.71$, $p < .025$, and a significant age × event interaction, $F(1, 28) = 5.93$, $p < .025$. Planned comparisons confirmed that the 12.5-month-olds who saw the change event ($M = 24.7$) looked reliably longer than those who saw the no-change event ($M = 9.3$), $F(1, 28) = 11.65$, $p < .005$, whereas the 11-month-olds who saw the change ($M = 14.9$) and no-change ($M = 15.0$) events looked about equally, $F(1, 28) = 0.00$. These results are consistent with previous findings (McCall, 2001; Wang *et al.*, 2005) that infants begin to attend to height information in covering events at about 12 months of age.

General discussion

The present experiments reveal a marked discrepancy in infants' ability to detect the same change in different events. The 11-month-olds in Experiment 1 detected a change to an object's height in an occlusion event, but appeared blind to the same change in a covering event; the 12.5-month-olds in Experiment 2 detected the change to the object's height in a covering but not a tube event. Prior reports indicate that infants typically identify the variable height at about 3.5 months in occlusion events, 12 months in covering events, and 14 months in tube events (e.g. Baillargeon & DeVos, 1991; Wang *et al.*, 2005). The present results are consistent with these findings, and as such support the prediction, derived from the reasoning account presented in the Introduction (e.g. Baillargeon, 2004; Wang *et al.*, 2005), that infants should detect a change to an object's height in an event only when they have identified height as a variable relevant to the event's category.

The present research thus extends prior demonstrations of knowledge effects in change detection in infants (e.g. Wilcox, 1999; Wilcox & Chapa, 2004), and is also consistent with demonstrations of expertise effects in adults (e.g. Jones, Jones, Smith & Copley, 2003; Werner & Thies, 2000). For example, Werner and Thies (2000) found that experts in the domain of American football were substantially better and faster than novices at detecting changes to images of football scenes, but not changes to domain-irrelevant traffic scenes.

What mechanism might underlie the physical knowledge effects demonstrated in the present research? Why do infants who have not yet identified a variable as relevant to an event category fail to detect surreptitious changes involving the variable when watching events from the category? A first possibility is that infants may fail to attend to and *encode* information about the variable. On this view, in each test trial, as the hand began lowering the cover/tube in front of or over the object, the infants categorized the event, determined (based on their prior knowledge) what variables were relevant to the event, and encoded information about these variables while the object was still in view. According to this analysis, the 11-month-olds in Experiment 1 thus encoded information about the heights of the cover/tube and object when watching the occlusion but not the covering events, and the 12.5-month-olds in Experiment 2 did the same when watching the covering but not the tube events.

A second possibility is that infants may fail to *retrieve* information about the variable. We have suggested elsewhere that when infants watch a physical event, different computational systems form different representations, for distinct purposes (e.g. Baillargeon *et al.*, in press; Wang *et al.*, 2005). In particular, infants' object-recognition system represents detailed information about the objects in the event, for recognition and categorization purposes; at the same time, infants' physical-reasoning system represents basic and variable information about the event, to predict and interpret its outcome. It is possible that when infants realize that they must include information about a variable in their physical representation of an event, and this information is no longer perceptually available (e.g. the object is now hidden and its initial height can no longer be encoded), they access their object-recognition system and retrieve the necessary information. On this view, all of the infants in the present research encoded information about the heights of the cover/tube and object in their object-recognition system (recall that the two stood side by side at the start of each event). After the hand lowered the cover/tube in front of or over the object, the infants (1) categorized the event; (2) determined which variables were relevant to the event; and (3), since the object was no longer visible, queried the object-recognition system for this variable information. Because the 11-month-olds in Experiment 1 had not yet identified height as a covering variable, and the 12.5-month-olds in Experiment 2 had not yet identified height as a tube variable, they did not retrieve height information from the object-recognition system when watching these events.

The two possibilities above are consistent with our account of infants' physical reasoning and more specifically with our claim that infants who have not yet identified a variable as relevant to an event category typically do not include information about the variable in their physical representations of events from the category. However, other possibilities exist that would call for a revision of our account; these possibilities are suggested by recent discussions of change detection in adults (e.g. Mitroff *et al.*, 2004; Simons & Ambinder, 2005; Simons & Rensink, 2005). One such possibility is that all of the infants in the present research attended to and included information about the initial height of the object in their physical representations of the test events; however, only infants who had identified height as a relevant variable were able to *retain* this information. Another possibility is that all of the infants in the present research represented and retained information about the initial height of the object; however, only infants who had identified height as a variable also (1) attended to and encoded information about the final height of the object, after the cover/tube was removed, and (2) *compared* the initial and final heights of the object.

Did the infants in the present research fail to detect the change to the object's height because they did not encode, retrieve, retain or compare the relevant height information? Although the present data are not sufficient to determine which of these four possibilities is correct, our intuition is that the first possibility is unlikely. Consider once again the events shown in the occlusion condition of Experiment 1. For the first possibility to hold, it would have to be the case that, in the very brief interval after the hand began to lower the cover in front of the object (recall that the cover was held only about 2.5 cm above the object) and before the object became partly hidden, the infants successfully (1) categorized the event as an occlusion event; (b) ascertained that height information was relevant to this event category; and (3) encoded information about the heights of the cover and object. Although it is in principle possible that the infants were able to do so, it seems more probable that they categorized the event as an occlusion event after the cover hid at least a portion of the object – too late to encode information about the heights of the cover and object. This analysis suggests that all of the infants in the present research encoded information about the initial heights of the cover and object – but only the infants in the occlusion condition of Experiment 1 and in the covering condition of Experiment 2 were able to retrieve, retain or compare this information as the event progressed. This analysis is also consistent with recent evidence that adults who appear unaware of a change may nonetheless give evidence that they encoded information relevant to the change (e.g. Hollingworth & Henderson, 2002; Mitroff *et al.*, 2004). Future experiments will explore which of the three remaining possibilities best describes how infants represent and process information about events, and hence why they detect some but not other surreptitious changes in these events.

Acknowledgements

This research was supported by grants from UCSC (FRG) to S.W. and from NICHD (HD-21104) to R.B. We thank Bruce Bridgeman and Steve Mitroff for helpful comments; the research staff at UCSC and UIUC for their help with data collection; and the parents and infants who participated in the research.

References

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

Baillargeon, R. (2004). Infants' reasoning about hidden objects: evidence for event-general and event-specific expectations. *Developmental Science*, **7**, 391–424.

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

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

Baillargeon, R., Li, J., Luo, Y., & Wang, S. (in press). Under what conditions do infants detect continuity violations? In M.H. Johnson & Y. Munakata (Eds.), *Processes of change in brain and cognitive development: Attention and performance XXI*. Oxford: Oxford University Press.

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

Bower, T.G.R. (1974). *Development in infancy*. San Francisco, CA: W.H. Freeman.

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

Goldberg, S. (1976). Visual tracking and existence constancy in 5-month-old infants. *Journal of Experimental Child Psychology*, **22**, 478–491.

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

Hespos, S.J., & Baillargeon, R. (in press). Décalage in infants' knowledge about occlusion and containment events: converging evidence from action tasks. *Cognition*.

Hollingworth, A., & Henderson, J.M. (2002). Accurate visual memory for previously attended objects in natural scenes. *Journal of Experimental Psychology: Human Perception and Performance*, **28**, 113–136.

Jones, B.T., Jones, B.C., Smith, H., & Copley, N. (2003). A flicker paradigm for inducing change blindness reveals alcohol and cannabis information processing biases in social users. *Addiction*, **98**, 235–244.

LeCompte, G.K., & Gratch, G. (1972). Violation of a rule as a method of diagnosing infants' level of object concept. *Child Development*, **43**, 385–396.

Leslie, A.M. (1994). ToMM, ToBY, and agency: core architecture and domain specificity. In L.A. Hirschfeld & S.A. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture* (pp. 119–148). New York: Cambridge University Press.

McCall, D. (2001, April). Perseveration and infants' sensitivity to cues for containment. Paper presented at the biennial meeting of the Society for Research in Child Development, Minneapolis, MN.

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

Meicler, M., & Gratch, G. (1980). Do 5-month-olds show object conception in Piaget's sense? *Infant Behavior and Development*, **3**, 265–282.

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

Muller, A.A., & Aslin, R.N. (1978). Visual tracking as an index of the object concept. *Infant Behavior and Development*, **1**, 309–319.

Needham, A. (1998). Infants' use of featural information in the segregation of stationary objects. *Infant Behavior and Development*, **21**, 47–75.

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

Rensink, R.A. (2002). Change detection. *Annual Review of Psychology*, **53**, 245–277.

Simon, T., Hespos, S.J., & Rochat, P. (1995). Do infants understand simple arithmetic? A replication of Wynn (1992). *Cognitive Development*, **10**, 253–269.

Simons, D.J. (2000). Current approaches to change blindness. *Visual Cognition: Special Issue on Change Detection and Visual Memory*, **7**, 1–16.

Simons, D.J., & Ambinder, M. (2005). Change blindness: theory and consequences. *Current Directions in Psychological Science*, **14**, 44–48.

Simons, D.J., & Levin, D.T. (1998). Failure to detect changes to people during a real-world interaction. *Psychonomic Bulletin and Review*, **5**, 644–649.

Simons, D.J., & Rensink, R.A. (2005). Change blindness: past, present, and future. *Trends in Cognitive Science*, **9**, 16–20.

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

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

Wang, S., & Baillargeon, R. (2005a). Can infants' physical knowledge be trained? Manuscript under review.

Wang, S., & Baillargeon, R. (2005b). Inducing infants to detect a physical violation in a single trial. *Psychological Science*, **16**, 542–549.

Wang, S., Baillargeon, R., & Brueckner, L. (2004). Young infants' reasoning about hidden objects: evidence from violation-of-expectation tasks with test trials only. *Cognition*, **93**, 167–198.

Wang, S., Baillargeon, R., & Paterson, S. (2005). Detecting continuity violations in infancy: a new account and new evidence from covering and tube events. *Cognition*, **95**, 129–173.

Werner, S., & Thies, B. (2000). Is 'change blindness' attenuated by domain-specific expertise? An expert–novices comparison of change detection in football images. *Visual Cognition*, **7**, 163–174.

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

Wilcox, T., & Chapa, C. (2002). Infants' reasoning about opaque and transparent occluders in an individuation task. *Cognition*, **85**, B1–B10.

Wilcox, T., & Chapa, C. (2004). Priming infants to attend to color and pattern information in an individuation task. *Cognition*, **90**, 265–302.

Received: 11 March 2005
Accepted: 4 August 2005