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Infants detect changes in everyday scenes: The role of scene gist

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A B S T R A C T

When watching physical events, infants bring to bear prior knowledge about objects and readily detect changes that contradict physical rules. Here we investigate the possibility that scene gist may affect infants, as it affects adults, when detecting changes in everyday scenes. In Experiment 1, 15-month-old infants missed a perceptually salient change that preserved the gist of a generic outdoor scene; the same change was readily detected if infants had insufficient time to process the display and had to rely on perceptual information for change detection. In Experiment 2, 15-month-olds detected a perceptually subtle change that preserved the scene gist but violated the rule of object continuity, suggesting that physical rules may overpower scene gist in infants' change detection. Finally, Experiments 3 and 4 provided converging evidence for the effects of scene gist, showing that 15-month-olds missed a perceptually salient change that preserved the gist and detected a perceptually subtle change that disrupted the gist. Together, these results suggest that prior knowledge, including scene knowledge and physical knowledge, affects the process by which infants maintain their representations of everyday scenes.

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1. Introduction

Visual experience is complex and ever changing as eyes switch focus from one point to another in the environment. Attending to all changes would be daunting and inefficient for the viewer; selective attention is necessary to process visual information rapidly in everyday life. Consequently, certain changes to a scene become prioritized over others in the visual representational system, and the viewer detects some changes while overlooking others (e.g., Hollingworth, 2003, 2006; Hollingworth & Henderson, 2000; Rensink, 2002; Simons & Ambinder, 2005; Wang & Mitroff, 2009). The present research investigates the developmental continuity in this prioritizing process and examines whether *scene gist* affects infants, as it affects adults, when they attend to everyday scenes.

In order to detect a change, the viewer needs to encode the pre-change information, maintain this information over time, and compare it to the post-change information (e.g., Simons & Ambinder, 2005). By manipulating contextual congruity and perceptual salience, prior research has gathered converging evidence showing that both knowledge- and perception-based processes can interfere with scene representation and affect change detection (Beck & Levin, 2003; Davenport & Potter, 2004; Hollingworth, 2003, 2006; Hollingworth & Henderson, 2000; Joubert, Rousselet, Fize, & Fabre-Thorpe, 2007; Mitroff, Simons, & Levin, 2004; Rensink, 2000, 2002; Simons & Ambinder, 2005). For example, identifying an object in a glimpse (80 ms) is less accurate when the object appears in an improbable than a probable scene (e.g., football player in the church versus in the football field), suggesting that scene congruity facilitates visual perception, whereas scene incongruity hinders the process and thereby calls for additional viewing time for scene representation (Davenport & Potter, 2004). Although perceptual features of a scene, such as color contrast, affect the viewer's ability to represent the details of the scene, knowledge plays a pivotal role in change detection (e.g., Nijboer, Kanai, de Haan, & van der Smagt, 2008; O'Regan, Rensink, & Clark, 1999).

It has been proposed that the initial representation of a scene includes the overall meaning of the scene—termed *scene gist*—in addition to its general perceptual characteristics (e.g., Hollingworth, 2006; Oliva, 2005; Rensink, 2000, 2002). For example, when the viewer recognizes a scene as related to *parks*, the gist of *a park scene* is extracted and serves as an overarching structure that guides scene representation. Consequently, changes that preserve the gist (e.g., trees replaced by water fountains) can be easily overlooked, whereas changes that disrupt the gist (e.g., trees replaced by bathroom sinks) may capture attention and be easily detected (Rensink, 2000; Simons, 2000). According to this view, perceptually salient changes may go undetected as long as the scene gist is preserved; supporting results have been widely obtained with adults, demonstrating a phenomenon termed *change blindness* (e.g., Levin & Simons, 1997; Sampanes, Tseng, & Bridgeman, 2008). For example, Levin and Simons (1997) showed that participants failed to notice a salient change when the sole actor in a video clip was changed between the scenes (e.g., in the first scene actor A leaves the office to answer a phone, and in the next scene actor B enters the hallway to pick up the phone). Even though the actor was the main feature of the event, the participants missed the change because the meaning of the event remained unchanged when the new actor carried out the unfinished action of the previous actor. Another implication of gist-guided representation is that change detection may vary across individuals as a function of scene knowledge. For example, viewers with expert knowledge (e.g., knowledge about football players' strategic positions) were quicker than novices at detecting changes that altered the overall scene meaning (Werner & Thies, 2000; see also Hollingworth & Henderson, 2000; Nijboer et al., 2008).

With limited knowledge, infants can be considered novices in many respects and assumed to rely primarily on perception-based processes for scene representation; however, it can be argued that infants also actively apply relevant knowledge in this process. On the one hand, the visual memory system undergoes rapid development during the first year, allowing infants to notice perceptually salient changes. By 3 months of age, infants perceive the visual world in rich color details as adults do (see Atkinson, 1998), with some acuity to identify and distinguish elements of a scene. Before the first birthday, their visual short-term memory reaches adult capacity, allowing them to track simultaneous changes to multiple visual stimuli (e.g., Cheries, Wynn, & Scholl, 2006; Ross-Sheehy, Oakes, & Luck, 2003). On the other hand, research has shown that infants' knowledge about the world mediates their representation of objects and events. For example, when infants watch objects move in relation to others, their existing knowledge about the physical event guides them to select and use relevant information in the event (Aguiar & Baillargeon, 2002, 2003; Baillargeon & Wang, 2002; Huettel & Needham, 2000; Wang & Baillargeon, 2006, 2008a, 2008b; Wang & Kohne, 2007; Wilcox, Woods, Chapa, & McCurry, 2007). It seems plausible that infants may also utilize a similar knowledge-based process in their scene representation.

A theoretical model has been proposed to specify how infants build representations of objects and events in the physical world (e.g., Baillargeon, Li, Ng, & Yuan, 2009; Baillargeon et al., 2012; Wang, 2011; Wang & Baillargeon, 2008b). The model posits that infants construct a unified representation of physical events through three computational systems. One of the systems, relevant to our focus here, is a physical-reasoning system that determines which information should be retrieved and included in the representation of the event. The physical-reasoning system is argued to develop as infants identify more and more variables that are relevant for predicting the outcomes of physical events. For example, infants recognize that the variable height is relevant for predicting the outcomes of occlusion events at 3.5 months of age, and for covering events at 12 months (e.g., Baillargeon & DeVos, 1991; Wang, Baillargeon, & Paterson, 2005). This knowledge affects infants' recruitment of height information: Infants between 3.5 and 12 months readily include height information in their representations when presented with occlusion events, but fail to do so when presented with covering events. Consequently, infants between 3.5 and 12 months detect a change to an object's height when it occurs in the context of occlusion events; however, they are blind to the same change when it occurs in the context of covering events (Wang & Baillargeon, 2006), even though infants appear to have encoded both the pre- and post-change heights (Wang & Mitroff, 2009). Together, these findings suggest that infants' physical knowledge mediates their representation of the events and guides them to detect some but not other changes. Of particular interest here is whether infants' knowledge about everyday scenes also mediates their representation and change detection.

A series of experiments demonstrated early sensitivity to everyday knowledge in the process of object segregation (e.g., Dueker, Modi, & Needham, 2003; Dueker & Needham, 2005; Needham, Cantlon, & Ormsbee Holley, 2006). For example, Needham et al. (2006) showed 8.5-month-old infants a display that resembled a partially occluded key ring (i.e., a wooden ring and three plastic keys with all contact points concealed). Because the contact points were not visible to infants, any connection between the ring and keys could only be inferred. Infants should perceive the displayed items as connected if they applied their knowledge about key chains; conversely, infants should perceive the items as separated if they focused on the perceptual differences between the items. The results indicated that when the ring was pulled away, infants looked significantly longer when the keys remained stationary than when they moved with the ring, suggesting that infants had expected a connection. These findings implied that infants use their knowledge about everyday objects—in this case, key chains—when processing object information.

In another set of experiments, 15-month-olds detected a violation when an actor pretended to pour liquid into one cup and drink from another cup, but not when the actor pretended to pour into one shoe and drink from another shoe—unless the shoe had been demonstrated as a drinking tool (Onishi, Baillargeon, & Leslie, 2007). Hence, at 15 months of age, infants detected a violation in an everyday activity (i.e., pouring into one cup and drinking from another) even when it involved pretense. Moreover, infants applied their knowledge about conventional functions of everyday objects when interpreting others' actions (i.e., cups serve as a conventional drinking vessel, whereas shoes typically do not).

In addition to applying knowledge about everyday objects, infants appear to form relational memory for different elements of a scene. Richmond and Nelson (2009) presented 9-month-old infants with human faces embedded in distinct scene contexts. After seeing three different face-scene pairings, one pairing at a time, the infants were tested with one of the scenes paired with the faces they just saw. The infants discriminated between familiar and novel pairings of scene elements and looked preferentially at the correct face-scene pairing, suggesting that they encoded the faces in conjunction with the other elements in the scene. It seems plausible that as infants observe the world, such relational memory may enable them to notice which elements typically occupy a particular kind of scene. For example, when infants are carried outside their homes, they may notice lawns, street signs, and trees. Over time, they may contrast these items with those inside their homes, such as chairs, bathtubs, and beds. Thus, just like categories of physical events and objects, infants may form categories of scenes (e.g., outdoor versus indoor scenes).

Indeed, as young children encounter similar events repeatedly, they acquire script knowledge—expectations about grouping and sequences of event elements, which in turn affects their representation of an event (e.g., Hudson, Fivush, & Kuebli, 1992; Hudson & Nelson, 1986; Hudson, Shapiro, & Sosa, 1995; Otgaar, Candel, Scoboria, & Merckelbach, 2010; see also Nguyen, 2012, for script categories). In a similar vein, knowledge about scene categories may help infants predict which items tend to co-exist in a scene and detect scene irregularities (i.e., the presence of an improbable scene element). Recent research by Bornstein, Mash, and Arterberry (2010, 2011) provides initial support for this possibility. Four-month-old infants' visual scanning patterns differed when objects were paired with congruent versus incongruent contexts (e.g., a tiger in the grass versus outside a city building), suggesting that infants are sensitive to object-scene congruity.

1.1. The present research

Building on the various results summarized in the previous section, the present research examined whether scene knowledge would guide infants' change detection with everyday scenes by (1) masking a change when the scene gist is preserved and (2) highlighting a change that disrupts the gist. For example, infants' knowledge about neighborhood parks would specify the items that tend to appear in such contexts. Items that are incongruent with outdoor scenes (e.g., bathroom sinks) may capture infants' attention more readily than may congruent items (e.g., water fountains). Consequently, it may seem more apparent to infants if an item in an outdoor scene is replaced by an incongruent item (e.g., a tree replaced by a bathroom sink) than if it is replaced by a congruent item (e.g., a tree replaced by a water fountain). In other words, prior knowledge about a scene may highlight certain changes over others and guide infants to detect some changes while missing others (see e.g., Biederman, 1972; Biederman, Glass, & Stacy, 1973; Joubert et al., 2007; Levin & Simons, 1997; Sampanes et al., 2008 for related research with adults). We tested this hypothesis in four experiments.

Experiment 1 examined the masking effect of scene gist and tested the prediction that when the gist is preserved, infants should be prone to miss the change even if it is perceptually salient. Experiment 2 examined potential limits of the masking effect. Experiment 3 examined the highlighting effect of scene gist and tested the prediction that when the gist is disrupted, infants should readily

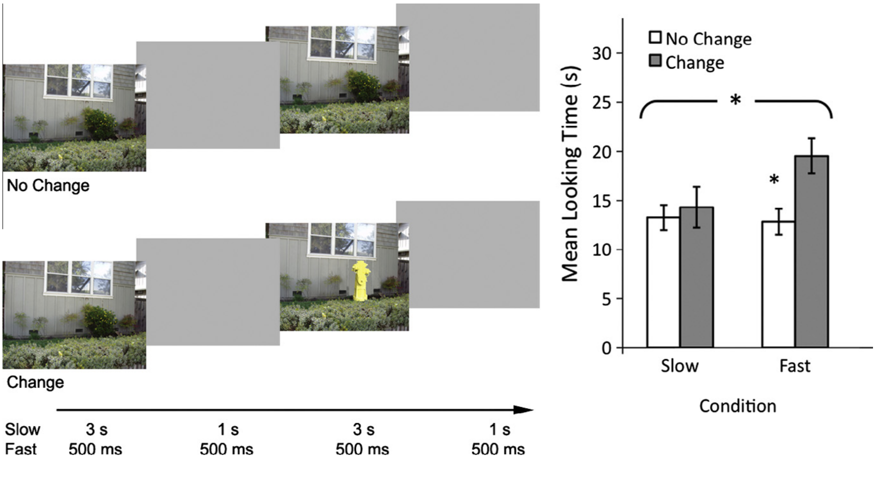

Fig. 1. Left panel displays image streams used in Experiment 1. Right panel shows the infants' mean looking times during the change and no-change test trials. An asterisk above the bar indicates that looking times differ significantly between the change and no-change trials ($p < .05$). The bracket with an asterisk indicates a significant effect of Condition × Trial Type interaction ($p < .05$). Error bars represent standard errors.

detect a change even if it is perceptually subtle. Finally, Experiment 4 extended the effects of scene gist to a different type of scene.

2. Experiment 1

Experiment 1 examined whether scene knowledge, once accessed, would hinder infants' detection of a gist-preserving change. Fifteen-month-old infants watched streams of outdoor photographs flashing on a computer screen. The pre-change picture depicted the lawn and shrubs in front of a house window—a scene that infants commonly see in everyday life. In the post-change picture, a shrub near the center of the picture was replaced by a yellow hydrant (see Fig. 1). All infants received two test trials: a change trial and a no-change trial. In the change trial, the pre- and post-change pictures appeared in alternation, resulting in the shrub being replaced by the hydrant in every other picture; in the no-change trial, the pre-change picture was displayed on and off the screen repeatedly. Note that the changes between a green shrub and a yellow hydrant should appear perceptually salient but pose little impact on the gist of *an outdoor scene*.[1] In other words, we pitted perceptual salience of the change against preservation of scene gist. If infants' change detection is guided by scene gist, they should miss the gist-preserving change despite its perceptual salience, demonstrating the masking effect of scene gist. However, when their access to scene knowledge is limited, the masking effect should dissipate.

To manipulate the level of access to scene knowledge, the infants were randomly assigned to one of two conditions, a *slow* and a *fast* condition. The two conditions differed in the following aspects. First, during the test trials, the pre- and post-change pictures were presented at a different pace across the two conditions. In the slow condition, each picture was displayed for 3 s with a 1-s Interstimulus Interval (ISI), whereas in the fast condition, each picture was displayed for 500 ms with a 500-ms ISI. Second, the infants in the slow condition received familiarization trials prior to the test trials. Each familiarization trial consisted of the still display of the pre-change picture to provide the infants with ample opportunity to access their knowledge about the scene. In contrast, the infants in the fast condition received test trials only and did not see the pre-change picture beforehand. We expected that in the slow condition, infants' change detection should be masked or hindered by the preservation of scene gist; as a result, they should miss the change and look about equally during the change and the no-change trial. In contrast, the infants in the fast condition should have limited access to scene knowledge. As a result, they should readily detect the change from the green shrub to the yellow hydrant, and look significantly longer during the change than the no-change trial.

2.1. Method

2.1.1. Participants

Participants were 30 healthy full-term infants (13 girls, 17 boys) ranging in age from 14 months 0 days to 16 months 23 days (M = 15 months 4 days). The age of 15 months was chosen based on research by Onishi et al. (2007), showing that infants this age readily use their knowledge about conventional functions of everyday objects. Fourteen of the infants were assigned to the slow condition (M = 15 months 3 days), and 16 to the fast condition (M = 15 months 4 days). Data from 12 additional infants were excluded due to fussiness ($n = 3$), outlier (more than 2.5 *SD*s different from the mean looking time of the condition, $n = 3$), inattentiveness ($n = 2$), exhausting the amount of time allowed on both test trials ($n = 2$), or low observability (i.e., observers had difficulty following the infant's gaze; $n = 2$).

In this and the following experiments, participants were predominantly Caucasians from middle-class families. We obtained infants' names from local birth announcements and parent groups, and

[1] As a manipulation check, 16 adults rated the perceptual salience of the changes. The pre- and post-change pictures used in Experiments 1–4 were presented in pairs, and the adults were asked to judge "how obvious the differences are" on a scale of 1 (*not at all obvious*) to 7 (*very obvious*). The order of presentation was approximately counterbalanced across raters. All of the results were consistent with our claims. The change between the shrub and the hydrant was rated as very obvious (M = 6.88, SE = 0.13)—more obvious than the shrub's disappearance in Experiment 2 (M = 5.19, SE = 0.48), $t(15) = 3.45$, $p < .005$, and the change between the hydrant and the mustard bottle in Experiment 3 (M = 6.06, SE = 0.17), $t(15) = 3.90$, $p < .005$. In Experiment 4, the change between the two umbrellas (M = 5.38, SE = 0.41) was rated as more obvious than the change between the umbrella and the table (M = 4.19, SE = 0.51), $t(15) = 2.76$, $p < .05$.

contacted parents by phone. Parents were offered small gifts or travel reimbursement, but were not otherwise compensated for participation.

2.1.2. Materials

The stimuli consisted of a digital color photograph and a solid gray picture (both measured 29 cm high × 39 cm wide) shown on a monitor. The color photograph was modified by Adobe Photoshop to produce the pre- and post-change pictures.

We used a 22-inch monitor (Samsung SyncMaster 2253LW) and a computer (Dell Latitude X300) to present the stimuli. The monitor was placed on a platform (94 cm above the floor) that was part of a wooden display booth (106 cm high × 100 cm wide × 46 cm deep). There was a large opening (41 cm × 95 cm) in the front of the booth; between trials, a fabric-covered wooden frame (61 cm × 99.5 cm) was lowered in front of this opening. The platform was covered with pastel contact paper, and the sidewalls were painted white. A white foam board was placed against the back of the monitor and used as the back wall, obscuring the computer from the infant's view; this board had a window (7 cm × 7 cm) near the bottom for the monitor cables to be pulled through the back wall. Two large fabric-covered frames (106 cm × 46 cm) were hinged to either side of the booth to separate the infant from the rest of the room. The sidewalls had a peephole (1 cm in diameter) through which the observers monitored the infant's eye gaze while remaining hidden from the infant's view. The parent sat on an adjustable-height chair while holding the infant in his or her lap; the infant's eye level was centered approximately 70 cm away from the monitor. Parents were asked to remain neutral and silent during all trials.

2.1.3. Procedure

In the slow condition, the infants first received three familiarization trials in which they watched a still display of the pre-change picture with the shrub. The same picture was displayed across familiarization trials. Each familiarization trial ended when the infants looked away for 2 consecutive seconds after having looked at the display for 6 cumulative seconds, or when they had looked at the display for 30 cumulative seconds.[2] In the fast condition, the infants did not receive familiarization trials.

During the test trials, all of the infants watched a stream of photographs separated by a solid gray picture. During the no-change test trial, the pre-change picture appeared on and off repeatedly (top array in Fig. 1). During the change test trial, the pre- and post-change pictures alternated in appearance after each gray mask (bottom array in Fig. 1). Within each condition, half of the infants received the change trial first, and half the no-change trial first. Each test trial ended when infants looked away for 1 consecutive second after having looked at the display for 8 cumulative seconds (for both conditions), or when they had looked at the display for 60 cumulative seconds (for the slow condition) or 30 cumulative seconds (for the fast condition).[3]

As mentioned before, two steps were taken to reduce the impact of scene knowledge in the fast condition. First, the infants in the fast condition received only test trials; the removal of the familiarization trials prevented them from accessing the overall meaning of the pre-change picture. Second, in the slow condition, the test pictures were shown for 3 s and the mask (gray solid image) for 1 s; in the fast condition, the test pictures and mask were displayed for 500 ms.[4] The elimination of familiarization trials and shortening of display duration should limit the infants' access to scene knowledge and

[2] On average, infants looked at the still display of the pre-change picture for 12.61–16.57 s (*SE*s = 0.93–1.06 s) per familiarization trial in the slow conditions across four experiments. In each condition, 1–4 infants reached the maximum looking time of 30 s per familiarization trial, but none of them did so on all three familiarization trials. Thus, there was little variability in infants' exposure to the pre-change picture across conditions.

[3] Different maximum trial lengths were used for the two conditions because the infants in the fast conditions tended to become fussy after prolonged exposure to fast-flashing pictures.

[4] In a series of experiments on infants' visual short-term memory, Oakes and colleagues (e.g., Oakes, Messenger, Ross-Sheehy, & Luck, 2009; Oakes, Ross-Sheehy, & Luck, 2006; Ross-Sheehy, Oakes, & Luck, 2011; Ross-Sheehy et al., 2003) displayed the images for 500 ms and the masks for 250–300 ms so that infants did not have enough time to access their long-term memory. Here, we also used the 500-ms display time for the images. However, with 250- to 300-ms ISIs, adult observers in our pilot study detected the change possibly by means of motion cues and iconic memory—the pre-change object appeared to shift its shape and boundaries back and forth between the pictures (see e.g., Hollingworth, 2006, p. 785 for a discussion on sensory persistence with adults). Therefore, we increased the ISI to 500 ms.

thereby guide them to rely primarily on perceptual information to detect the change in the fast condition.

Two observers monitored the infant's eye gaze through peepholes in the fabric-covered frames and pressed a button linked to a computer whenever the infant looked at the display; the observers were not aware of which pictures the infant saw during the test trials. The computer calculated online the total duration over which the infant looked at the display and terminated the trial when one of the above criteria was met based on the input from the primary (and typically more experienced) observer. Interobserver agreement in this and the following experiments averaged 92.08% per test trial per infant (SE = 0.38%).

Preliminary data analyses revealed no significant interaction involving sex and trial type in this and the following experiments, $ps > .05$; thus, the data were collapsed across sex in subsequent analyses. An alpha level of .05 (two-tailed) was used for all analyses.

2.2. Results and discussion

The infants' mean looking times during the test trials (see Fig. 1) were analyzed by a $2 \times 2 \times 2$ mixed model analysis of variance (ANOVA) with condition (slow or fast) and order (change or no-change trial first) as between-subjects factors, and trial type (change or no-change) as a within-subject factor. The analysis yielded a significant Condition × Trial Type interaction, $F(1,26) = 6.01$, $p < .05$, $\eta^2 = .13$. Planned comparisons indicated that the infants in the fast condition looked significantly longer during the change (M = 19.53 s, SE = 1.79 s) than the no-change (M = 12.83 s, SE = 1.31 s) trial, $F(1,26) = 18.11$, $p < .001$, Cohen's d = 1.01, whereas those in the slow condition looked about equally during the two trials (change: M = 14.31 s, SE = 2.08 s; no-change: M = 13.26 s, SE = 1.28 s), $F(1,26) = 0.39$, $p > .35$, d = 0.19. Nonparametric Wilcoxon signed-ranks tests confirmed these results: Whereas 13 of the 16 infants in the fast condition looked longer during the change trial than the no-change trial (T = 12.50, $p < .005$), only 6 of the 14 in the slow condition did so (T = 48.00, $p > .75$).

The results supported our prediction that the infants in the fast condition should notice the change, whereas those in the slow condition should not. Although the infants in the fast condition had very limited time to look at the pre- and post-change pictures (500 ms per flashing), they detected the change when the green shrub was replaced by the yellow hydrant, suggesting that the change was salient enough for 15-month-olds' visual system. However, when given ample time to view the pictures, the infants in the slow condition were blind to the change. Together, these results provided initial support for our prediction that when infants have access to scene knowledge, they should be prone to miss a gist-preserving change even if it is perceptually salient.

The findings of Experiment 1 implied that in everyday viewing, when infants have adequate time to construe their visual experience, a change that preserves the overall meaning of a scene could be easily overlooked. However, change blindness derived from preserving the scene gist may have limits when the change is flagged by other knowledge infants possess, such as their physical knowledge. As summarized in the Introduction, infants as young as a few months old already acquire primitive knowledge about how objects should behave and interact with each other. Their physical knowledge, likely more robust than scene knowledge, may flag certain gist-preserving changes and thereby enable infants to detect the changes. Experiment 2 examined this possibility.

3. Experiment 2

One of the basic physical rules infants acquire at a very young age is the principle of continuity—objects continue to exist over time and space (Aguiar & Baillargeon, 1999, 2002; Baillargeon & DeVos, 1991; Wang, Baillargeon, & Brueckner, 2004; Wang et al., 2005; see also Baillargeon et al., 2009; Spelke, 2000; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Spelke, Katz, Purcell, Ehrlich, & Breinlinger, 1994; Wang & Baillargeon, 2008b). In the study by Wang and colleagues (2005), for example, 3-month-old infants saw a cover being lowered over a toy duck on a platform and then slid across the platform. When the cover was lifted, infants who saw the empty platform looked longer at the scene than did those who saw the duck on the platform, suggesting that they noticed the

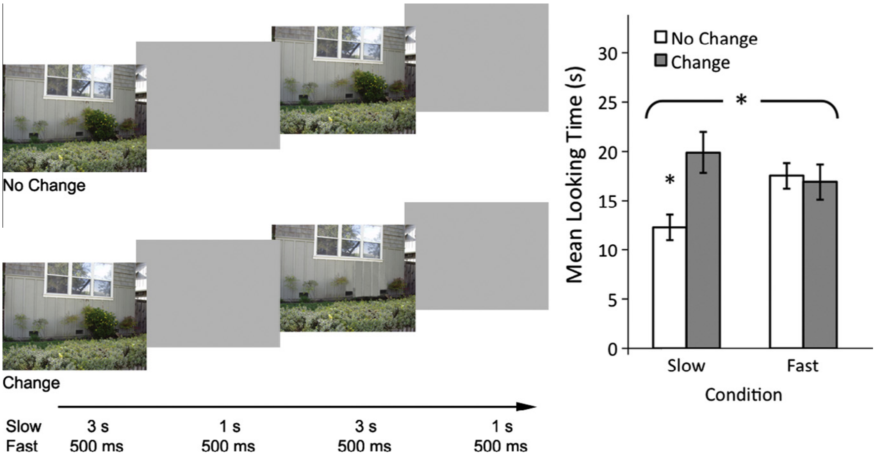

Fig. 2. Left panel displays image streams used in Experiment 2. Right panel shows the infants' mean looking times during the change and no-change test trials. An asterisk above the bar indicates that looking times differ significantly between the change and no-change trials ($p < .05$). The bracket with an asterisk indicates a significant effect of Condition × Trial Type interaction ($p < .05$). Error bars represent standard errors.

disappearance of the duck. Converging evidence has been obtained using a wide variety of tasks, showing that infants readily apply their knowledge about object continuity and detect the change when an object fails to reappear after being hidden from view briefly (Aguiar & Baillargeon, 1999, 2002; Baillargeon & DeVos, 1991; Luo & Baillargeon, 2005). In Experiment 2, we asked whether this powerful principle of continuity would flag a change that violates the principle and enhance infants' change detection when the scene gist is preserved.

Fifteen-month-old infants watched alternating outdoor pictures flashing on the computer screen, and a shrub near the center of the scene disappeared in every other picture (see Fig. 2). The pre-change picture was identical to that in Experiment 1. In the post-change picture, the shrub near the center was deleted from the scene without any replacement. Therefore, the total number of objects in the scene changed between pictures, contradicting the principle of continuity.

As with Experiment 1, we compared infants' change detection in two conditions. In the slow condition, the infants were given ample opportunity to inspect the pictures and access their knowledge. They watched a still display of the pre-change picture over three familiarization trials; during the two test trials, the pictures stayed on for 3 s with a 1-s ISI. In the fast condition, however, the infants received only two test trials wherein the pictures were displayed for 500 ms with a 500-ms ISI. This design allowed us to test whether infants' detection of the shrub disappearing in the picture would be affected by the amount of time allowed for them to access their physical knowledge. Given that adult participants regarded the shrub's disappearance as perceptually subtle (see Footnote 1), we expected that the infants in the fast condition should have difficulty detecting the change and should thus look about equally during the change and no-change trials. In contrast, even though the disappearance of the shrub was subtle to the visual system and did not disrupt the gist of the scene, we expected that physical knowledge about object continuity should flag this change. As a result, the infants in the slow condition should detect the change and look significantly longer during the change than the no-change trial.

The design of Experiment 2 also helped rule out an alternative explanation for the results of Experiment 1. Recall that the infants in Experiment 1 detected the change in the fast but not the slow condition. An alternative explanation of this response pattern could be a memory effect: The longer time interval between each test picture weakened infants' memory of the previous picture, making it difficult for them to detect the change. Based on this reasoning, the infants in Experiment 2 should detect the change in the fast but not the slow condition, which is opposite to our prediction.

3.1. Method

Participants were a new group of 32 healthy full-term infants (18 girls, 14 boys) ranging in age from 14 months 5 days to 16 months 11 days (M = 15 months 8 days). The infants were randomly assigned to the slow ($n = 16$) or the fast condition ($n = 16$). Data from eight additional infants were excluded due to fussiness ($n = 4$), parental interference ($n = 1$), inattentiveness ($n = 2$), or low observability ($n = 1$).

The materials and procedure were similar to those of Experiment 1, except for the post-change picture. In the pre-change picture, a shrub stood near the center in front of the building wall; in the post-change picture, the shrub was deleted (instead of being replaced by the hydrant), revealing the background of the gray house exterior (see Fig. 2). As in Experiment 1, the same pictures were used for both conditions, but the infants' exposure to the pictures differed between the conditions. The infants in the slow condition received three familiarization trials that consisted of a still display of the outdoor picture with a shrub near the center. Then, during the no-change test trial, the pre-change picture flashed on the screen repeatedly; during the change test trial, the pre-change and post-change picture flashed and alternated in appearance, making the shrub disappear in every other picture. In the test trials, each picture appeared for 3 s and was followed by a 1-s gray mask. The infants in the fast condition received no familiarization trials and completed only the two test trials wherein each picture and mask appeared for 500 ms. Within each condition, half of the infants received the change trial first, and half the no-change trial first.

3.2. Results and discussion

The infants' looking times during the test trials (see Fig. 2) were analyzed as in Experiment 1. The analysis revealed a significant Condition $\times$ Trial Type interaction, $F(1,28) = 5.99$, $p < .05$, $\eta^2 = .13$.[5] Planned comparisons indicated that the infants in the slow condition looked significantly longer during the change ($M = 19.88$ s, $SE = 2.83$ s) than the no-change ($M = 12.29$ s, $SE = 1.15$ s) trial, $F(1,28) = 10.25$, $p < .005$, $d = 0.83$, whereas those in the fast condition looked about equally during the two trials (change: $M = 16.91$ s, $SE = 1.89$ s; no-change: $M = 17.53$ s, $SE = 1.86$ s), $F(1,28) = 0.07$, $p > .50$, $d = 0.06$. Wilcoxon signed-ranks tests confirmed these results: Whereas 13 of the 16 infants in the slow condition looked longer during the change than the no-change trial ($T = 13.00$, $p < .005$), only 7 of the 16 in the fast condition did so ($T = 59.50$, $p > .65$).

The infants in the slow condition noticed the change when the shrub disappeared, whereas those in the fast condition did not. The results suggested that when the scene gist was preserved, the infants in Experiment 2 could still apply their physical knowledge and detect a perceptually subtle change that violated the principle of continuity. This finding contrasted with that of Experiment 1, showing that infants *can* detect gist-preserving changes that are flagged by their physical knowledge.

Two additional analyses were conducted to examine the roles of knowledge and perceptual salience. The first analysis directly contrasted the impact of scene knowledge and physical knowledge on infants' change detection: We compared the looking times of the infants in the slow conditions of Experiments 1 and 2, by a 2 $\times$ 2 $\times$ 2 ANOVA with experiment (Experiment 1 or 2) and order (change or no-change first) as between-subjects factors, and trial type (change or no-change) as a within-subject factor. The analysis yielded a significant Experiment $\times$ Trial Type interaction, $F(1,26) = 6.88$, $p < .05$, $\eta^2 = .12$. Planned comparisons indicated that the infants in Experiment 2 looked significantly longer during the change than the no-change trial ($d = 0.83$), whereas those in Experiment 1 looked

[5] There was a significant Trial Type $\times$ Order interaction, $F(1,28) = 5.03$, $p < .05$, $\eta^2 = .11$. Infants who received the change trial first looked longer during the change ($M = 21.43$ s, $SE = 2.94$ s) than the no-change ($M = 14.19$ s, $SE = 1.51$ s) trial, $F(1,28) = 9.32$, $p < .005$, $d = 0.64$, whereas those who received the no-change trial first looked about equally during the two trials (change: $M = 15.35$ s, $SE = 1.41$ s; no-change: $M = 15.63$ s, $SE = 1.83$ s), $F(1,28) = 0.01$, $p > .90$, $d = 0.03$. Our interpretation of the order effect was that infants became inattentive after the no-change trial, in which the same pre-change flashed repeatedly. Thus, when the no-change trial was presented first, infants' ability to detect the change in the subsequent trial was weakened. A similar order effect was observed in Experiment 3a and Experiment 4. However, because these effects did not interact with condition, they did not influence our interpretations of the results and will not be discussed further. Such order effects are not uncommon in infancy research (e.g., Aguiar & Baillargeon, 1999, 2002, 2003; also Csibra, Gergely, Biro, Koos, & Brockbank, 1999; Gergely, Nadasdy, Csibra, & Biro, 1995).

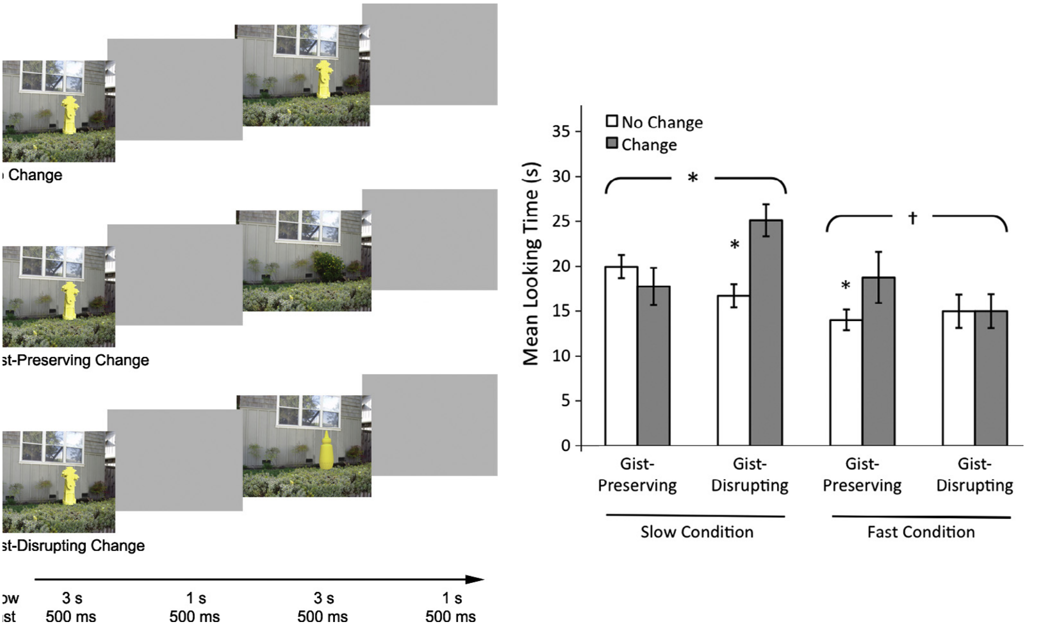

Fig. 3. Left panel displays image streams used in Experiment 3. Right panel shows the infants' mean looking times during the change and no-change test trials. An asterisk above the bar indicates that looking times differ significantly between the change and no-change trials ($p < .05$). The bracket with an asterisk indicates a significant effect of Group × Trial Type interaction ($p < .05$), and the bracket with a dagger indicates a marginal Group × Trial Type interaction ($p < .10$). Error bars represent standard errors.

about equally during the two trials ($d = 0.19$). Even though the scene gist was preserved in both experiments, the infants in the slow condition of Experiment 2 detected the change when the shrub disappeared (hence violating the principle of continuity), whereas the infants in Experiment 1 missed the change when the shrub was replaced by a gist-congruent item. Therefore, knowledge about object continuity allowed the 15-month-olds to detect a change even when the scene gist was preserved.

For adults, the change from the shrub to the hydrant in Experiment 1 was more salient than the disappearance of the shrub in Experiment 2 (see Footnote 1). To examine the impact of perceptual salience, we compared the looking times of the infants in the fast conditions of Experiments 1 and 2 by the same 2 × 2 × 2 ANOVA as above. This second analysis yielded a significant Experiment × Trial Type interaction, $F(1,28) = 5.12$, $p < .05$, $\eta^2 = .13$. Planned comparisons indicated that the infants in Experiment 1 looked significantly longer during the change than the no-change trial ($d = 1.01$), whereas those in Experiment 2 looked about equally during the two trials ($d = 0.06$). Thus, when there was inadequate time to access knowledge, perceptual salience predominately affected whether infants detected the change or not. This finding ruled out the alternative memory explanation for the results of Experiment 1, indicating that change blindness shown by the infants in the slow condition of Experiment 1 was not due to the interval being too long for infants to remember the previous picture.

Experiments 1 and 2, together, showed that 15-month-old infants' ability to detect changes in everyday scenes is affected by both knowledge- and perception-based factors. Expectedly, infants are better at detecting perceptually salient than perceptually subtle changes in general, as shown in the fast conditions. When there is adequate time to access their scene knowledge, as in the slow conditions, infants are prone to miss a gist-preserving change even if it is perceptually salient. However, the masking effect of scene gist may not occur when the gist-preserving change contradicts the basic principle of continuity, suggesting that physical knowledge can flag a gist-preserving change and override the effect of scene gist.

4. Experiment 3

The purpose of Experiment 3 was twofold: (1) to confirm the masking effect of scene gist, and (2) to test the other prediction of our hypothesis—that scene knowledge should highlight changes that disrupt the gist and make it easier for infants to detect changes even if they are perceptually subtle. To manipulate the level of access to scene knowledge, 15-month-old infants were randomly assigned to the slow or the fast condition as in the previous experiments. In Experiment 3 though, infants in each condition were randomly divided into two groups. One group of infants was presented with a change that preserved the scene gist (gist-preserved group), whereas the other group was presented with a change that disrupted the scene gist (gist-disrupted group). Specifically, the gist-preserved group saw the same pictures as those in Experiment 1, except that they were presented in a reversed order. The pre-change picture featured the yellow hydrant near the center of the scene, and the post-change the green shrub (see Fig. 3). In contrast, the gist-disrupted group saw a pre-change picture with the yellow hydrant and a post-change picture in which a yellow mustard bottle (a gist-incongruent item) replaced the hydrant.

We hypothesized that scene knowledge, once accessed, should affect infants' change detection in two opposing ways. As shown in Experiment 1 and to be confirmed here, when the gist is preserved, infants should be prone to change blindness—missing a gist-preserving change even if it is perceptually salient. On the other hand, when the gist is disrupted, infants should readily detect a change even if it is perceptually subtle. Therefore, we expected that in the slow condition, the gist-preserved group should miss the change when the hydrant was replaced by the shrub, whereas the gist-disrupted group should readily detect the change when the hydrant was replaced by the mustard bottle. In the fast condition, however, infants' change detection should be predominately driven by perceptual salience. Therefore, we expected the opposite pattern: The gist-preserved group should detect the change from the yellow hydrant to the green shrub, whereas the gist-disrupted group should miss the change from the yellow hydrant to the yellow mustard bottle.

4.1. Method

Participants were a new group of 64 healthy full-term infants (25 girls, 39 boys) ranging in age from 14 months 2 days to 16 months 10 days (M = 15 months 5 days). Half of the infants were assigned to the slow condition, and half to the fast condition. The infants in each condition were randomly divided into two groups: the gist-preserved group (slow: n = 16, M = 15 months 3 days; fast: n = 16, M = 15 months 5 days) and the gist-disrupted group (slow: n = 16, M = 15 months 6 days; fast: n = 16, M = 15 months 6 days). Data from 18 additional infants were excluded due to fussiness (n = 5), inattentiveness (n = 4), low observability (n = 4), exhausting the amount of time allowed on both test trials (n = 3), parental inference (n = 1), or outlier (n = 1).

The materials and procedure were similar to those in Experiment 1, except for the pre- and post-change pictures (see Fig. 3). The pre-change picture was the same in both slow and fast conditions. It depicted the lawn and shrubs outside of a house window, and near the center of the picture was a yellow hydrant. The post-change picture varied depending on the group to which the infants were assigned. The gist-preserved group saw the hydrant being replaced by the green shrub (a gist-congruent item), whereas the gist-disrupted group saw the hydrant replaced by a mustard bottle in comparable size and color (a gist-incongruent item).

As in Experiment 1, the infants in the slow condition, regardless of their assigned group, received three familiarization trials and two test trials. The familiarization trials consisted of a still display of the pre-change picture with the hydrant near the center. During the no-change test trial, the pre-change picture flashed on the screen repeatedly; during the change test trial, the pre-change and post-change picture flashed and alternated in appearance. In the test trials, the pictures stayed on for 3 s, separated by 1-s masks. The infants in the fast condition received only the two test trials, in which each picture and mask appeared for 500 ms. Within each group, half of the infants received the change trial first, and half the no-change trial first.

4.2. Results and discussion

The infants' looking times during the test trials (see Fig. 3) were analyzed, separately for each condition, using a $2 \times 2 \times 2$ mixed model ANOVA with group (gist-disrupted or gist-preserved) and order (change or no-change trial first) as between-subjects factors, and trial type (change or no-change) as a within-subject factor. In the slow condition, the analysis yielded a significant Group × Trial Type interaction, $F(1,28) = 4.44$, $p < .05$, $\eta^2 = .11$. Planned comparisons indicated that the infants in the gist-disrupted group looked significantly longer during the change ($M = 25.10$ s, $SE = 3.90$ s) than the no-change ($M = 16.71$ s, $SE = 2.93$ s) trial, $F(1,28) = 5.57$, $p < .05$, $d = 0.71$, whereas those in the gist-preserved group looked about equally during the two trials (change: $M = 17.74$ s, $SE = 2.51$ s; no-change: $M = 19.95$ s, $SE = 3.32$ s), $F(1,28) = -0.39$, $p > .50$, $d = 0.13$. Wilcoxon signed-ranks tests confirmed these results: Whereas 11 of the 16 infants in the gist-disrupted group looked longer during the change trial than the no-change trial ($T = 18.00$, $p < .05$), only 7 of the 16 in the gist-preserved group did so ($T = 62.00$, $p > .75$).[6] Consistent with our prediction for the slow condition, the gist-disrupted group noticed the change, whereas the gist-preserved group did not.

In the fast condition, the analysis yielded a marginal Group × Trial Type interaction, $F(1,28) = 3.36$, $p < .08$, $\eta^2 = .09$. Planned comparisons indicated a response pattern opposite to that of the slow condition: The infants in the gist-preserved group looked significantly longer during the change ($M = 18.74$ s, $SE = 1.60$ s) than the no-change ($M = 14.02$ s, $SE = 1.17$ s) trial, $F(1,28) = 6.76$, $p < .05$, $d = 0.72$, whereas those in the gist-disrupted group looked about equally during the two trials (change: $M = 14.99$ s, $SE = 1.89$ s; no-change: $M = 14.98$ s, $SE = 1.46$ s), $F(1,28) < .01$, $p > .95$, $d < 0.01$. Wilcoxon signed-ranks tests also confirmed these results: Whereas 12 of the 16 infants in the gist-preserved group looked longer during the change trial than the no-change trial ($T = 22.50$, $p < .05$), only 7 of the 16 in the gist-disrupted group did so ($T = 64.00$, $p > .80$). Consistent with our prediction for the fast condition, the gist-preserved group noticed the change, whereas the gist-disrupted group did not.

The results confirmed the masking effect shown in Experiment 1: Scene knowledge may increase the likelihood for infants to miss changes that preserve the gist. In Experiment 3, after seeing the pre-change picture with the hydrant for three familiarization trials, the infants in the slow condition missed the change when the green shrub replaced the yellow hydrant, whereas the infants in the fast condition detected the exact same change. On the flip side, Experiment 3 demonstrated the highlighting effect of scene gist: Scene knowledge can enhance infants' ability to detect changes that disrupt the gist. After seeing the pre-change picture with the hydrant for three familiarization trials, the infants in the slow condition detected the change when the mustard bottle, a gist-incongruent item, replaced the hydrant, whereas the infants in the fast condition missed the exact same change.

Together, the results in Experiment 3 provided compelling support for our hypothesis that scene gist affects 15-month-old infants' ability to detect changes to an everyday scene. When the infants were given the opportunity to watch a scene and access their knowledge about the scene (slow condition), they applied their knowledge and detected a perceptually subtle change that was incongruent with the scene context. Such a subtle change would have been easily missed if infants had limited access to their scene knowledge in the change-detection process (fast condition).

One of the limitations of Experiment 3 was that in matching the sizes of the hydrant and the mustard bottle, we had to present the mustard bottle in the post-change picture in an unusually large size. One could argue that the infants were better at detecting the hydrant-to-mustard-bottle change than the hydrant-to-shrub change because they had noticed the novel size of the mustard bottle. In other words, it could have been the unusual property of the object, rather than the incongruity with the gist, that enhanced infants' change detection. We addressed this issue in Experiment 4, by using a gist-incongruent item in its normal size.

[6] Of the 16 infants included in the gist-disrupted condition, 1 infant did not differentiate looking times between the change and no-change trials and was therefore excluded from the Wilcoxon signed-ranks test (see e.g., Conover, 1980, p. 280).

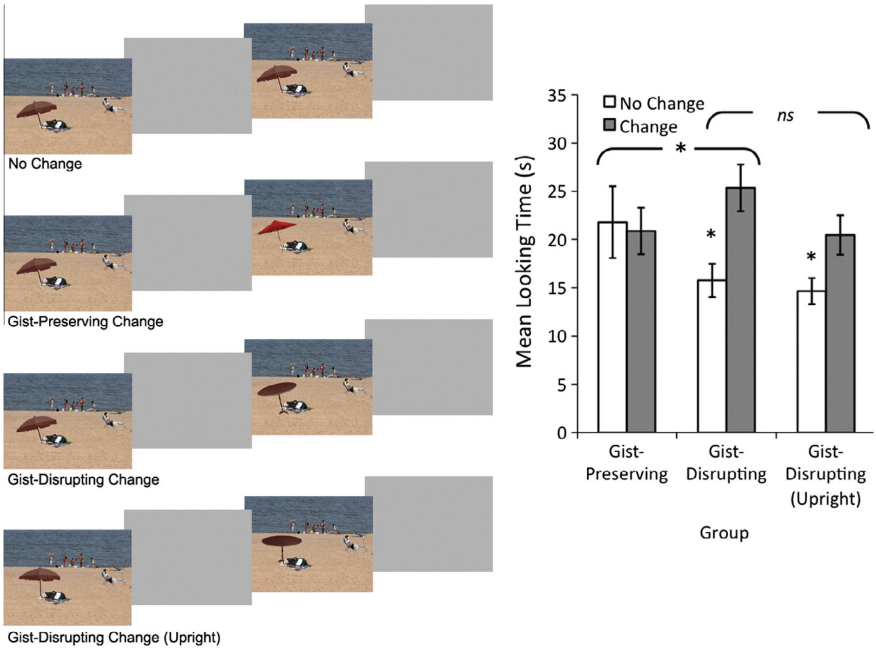

Fig. 4. Left panel displays image streams used in Experiment 4. Right panel shows the infants' mean looking times during the change and no-change test trials. An asterisk above the bar indicates that looking times differ significantly between the change and no-change trials ($p < .05$). The bracket with an asterisk indicates a significant effect of Group × Trial Type interaction ($p < .05$). Error bars represent standard errors.

5. Experiment 4

The primary goal of Experiment 4 was to extend our findings to a different type of everyday scene. Fifteen-month-old infants watched pictures of a *beach* scene in the slow pace and were randomly assigned to the gist-preserved or the gist-disrupted group, allowing us to examine the masking and highlighting effects of scene gist. To avoid the potential confound of object incongruity, we carefully selected the pre- and post-change objects in Experiment 4 so that the objects always appeared in their normal sizes.

The pre-change picture depicted the ocean and beach with people engaging in various activities; near the center of the picture was a beach umbrella (see Fig. 4). The same pre-change picture was used for both groups. In the post-change picture, the umbrella was replaced by another umbrella in different color and shape (gist-preserved group) or by a dining table matched in color and size (gist-disrupted group). As with the previous experiments, we pitted perceptual salience against gist disruption by making the post-change umbrella visually more different than the dining table from the original umbrella, such that the gist-congruent change was perceptually more salient than the gist-incongruent change.

Because the goal of Experiment 4 was to extend the effects of scene gist to the beach scene, the infants in both groups were given ample opportunity to look at the pre-change picture and access their scene knowledge during the three familiarization trials, and the test trials were administered as in the slow conditions of Experiments 1–3. We predicted that it would be easier for the infants to detect a perceptually subtle change that disrupted the scene gist than a perceptually salient change that preserved the gist. Consequently, the gist-disrupted group should look significantly longer during the change than the no-change test trial, whereas the gist-preserved group should look about equally during the two test trials.

5.1. Method

A new group of 32 infants (15 girls, 17 boys; M = 15 months 4 days; range: 14 months 0 days to 16 months 8 days) were randomly assigned to the gist-preserved group (n = 16, M = 15 months 0 days) or the gist-disrupted group (n = 16, M = 15 months 9 days). Data from two additional infants were excluded due to fussiness (n = 1) or low observability (n = 1).

A parental survey was conducted to gather information about each infant's exposure to beach scenes. Parents reported the number of times infants had been to the beach (a) in the preceding six months and (b) since infants were born, with possible responses for both questions being: *never*, 1–3 *times*, 4–6 *times*, 7–9 *times*, 10+ *times*. In the preceding six months, the majority of the infants had visited the beach four or more times (n = 12 for both groups), and all but 3 of the infants in the gist-disrupted group had made one or more visits. Since they were born, many of the infants had made more than 10 visits to the beach (n = 9 and n = 8, for the gist-preserved and the gist-disrupted group, respectively). Only 2 infants in the gist-disrupted group had never visited the beach.

The remaining aspects of the procedure were similar to those in the slow conditions of Experiments 1–3, except that different pictures were used (see Fig. 4). The pre-change picture depicted a beach scene with ocean, sand, people, and a brown curved beach umbrella. The umbrella was replaced, in the post-change picture, by either a red pointed beach umbrella (gist-preserved group) or a brown curved dining table (gist-disrupted group). The post-change objects were designed to pit perceptual salience against gist disruption. The responses of the adult raters confirmed that the manipulation was effective: The gist-preserving change from one umbrella to the other was rated as more obvious than the gist-disrupting change from the umbrella to the table (see Footnote 1).

All of the objects in the pictures maintained their regular sizes. The focal objects (i.e., umbrellas and table) were tilted counterclockwise by 13 degrees to accentuate their presence among other visually compelling elements of the scene, such as people and the brightly colored sand. The same rotation was performed for both groups.

5.2. Results and discussion

The infants' looking times during the test trials (see Fig. 4) were analyzed as in the slow condition of Experiment 3. The analysis revealed a significant Group × Trial Type interaction, $F(1,28) = 5.18$, $p < .05$, $\eta^2 = .11$. Planned comparisons indicated that the gist-disrupted group looked significantly longer during the change (M = 25.35 s, SE = 2.42 s) than the no-change (M = 15.76 s, SE = 1.72 s) trial, $F(1,28) = 8.63$, $p < .01$, $d = 0.82$, whereas the gist-preserved group looked about equally during the two trials (change: M = 20.88 s, SE = 2.41 s; no-change: M = 21.79 s, SE = 3.71 s), $F(1,28) = 0.08$, $p > .75$, $d = 0.05$. The results were confirmed by Wilcoxon signed-ranks tests: Whereas 13 of the 16 infants in the gist-disrupted group looked longer during the change than the no-change trial (T = 16.00, $p < .01$), only 9 of the 16 infants in the gist-preserved group did so (T = 66.00, $p > .90$).

5.2.1. Additional data

It is remarkable that the infants in the gist-disrupted group detected the change given that the umbrella and the table looked similar in overall shape and color. Indeed, our adult participants considered the umbrella-to-table change the subtlest of all changes (see Footnote 1). However, one might argue that the tilted position of the table might be visually novel and could have caused infants' prolonged looking for one of the following reasons. First, infants might have a difficulty recognizing it as a table and thus needed longer processing time. Second, infants might have applied their knowledge about force and expected the tilted table to fall in the sand, and might have been intrigued when it did not fall in subsequent pictures. To test these alternative interpretations, we conducted an additional condition in which both the umbrella and table stood straight upright (see Fig. 4). If the tilted position of the table had contributed to the positive result in Experiment 4, the infants in the upright condition should look about equally during the change and no-change trials. Conversely, if the disruption of scene gist was driving their change detection, the infants in the upright condition should still detect the change and look significantly longer during the change than the no-change trial.

Sixteen infants (8 girls, 8 boys; M = 15 months 6 days; range: 14 months 5 day–16 months 8 days) participated in the upright condition. Data from five additional infants were excluded due to inattentiveness ($n = 4$) or parental interference ($n = 1$). Like the other two groups, the majority of the infants had visited the beach more than 10 times since they were born ($n = 13$), and four or more times in the preceding six months ($n = 15$). Only one infant had never visited the beach.

The infants' looking times during the change and the no-change trial were compared using a paired samples t-test. The test indicated that the infants looked significantly longer during the change ($M = 20.47$ s, $SE = 2.05$ s) than the no-change ($M = 14.65$ s, $SE = 1.35$ s) trial, $t(15) = 2.20$, $p < .05$, $d = 0.57$; 12 of the 16 infants looked longer during the change than the no-change trial (Wilcoxon signed-ranks test, $T = 28.00$, $p < .05$). The infants' looking times were also compared with the other gist-disrupted group who saw the tilted umbrella replaced by the tilted table, by a $2 \times 2 \times 2$ mixed model ANOVA, with condition (tilted or upright) and order (change first or no-change first) as between-subjects factors, and trial type (change or no-change) as a within-subject factor. No significant effect involving condition was found. Thus, when the gist was disrupted, the infants responded with a similar looking-time pattern whether the table was tilted or upright.

The 15-month-old infants in Experiment 4 missed the change when the beach umbrella was replaced by another umbrella even though they were different in color and shape. In contrast, they readily detected the change when the beach umbrella was replaced by the dining table in the same color and similar shape. These results extended the masking and highlighting effects of scene gist demonstrated in Experiments 1 and 3 from a generic outdoor scene to a beach scene, and provided converging evidence for the knowledge-based processes in infants' scene representation and change detection. The findings thus underscored the important role of scene gist in infants' ability to detect changes in everyday scenes.

6. General discussion

The primary goal of the present research was to examine the role of scene gist in infants' representation of everyday scenes. Using the change-detection task, we investigated two potential effects—masking and highlighting effects—of scene gist on 15-month-old infants' change detection. In Experiment 1, the infants missed a perceptually salient change when they were given the opportunity to access scene knowledge; the change was otherwise readily detected when they had very little time to access their knowledge about the scene. The results demonstrated the masking effect of scene gist, suggesting that scene knowledge could overrule perceptual salience in the process of representing everyday scenes. In Experiment 2, knowledge about object continuity allowed the infants to detect a gist-preserving change, suggesting that physical knowledge might overpower scene knowledge and enhance infants' change detection by flagging changes that violate basic object principles. Finally, Experiments 3 and 4 demonstrated both masking and highlighting effects of scene gist across two types of scenes: Whether the infants detected a change depended on whether the scene gist was disrupted, and not on whether the change was perceptually salient. Together, the present findings provided compelling evidence for the hypothesis that scene gist affects infants, as it affects adults, when they attend to everyday scenes.

The present research used looking times as the dependent measure. As with any indirect measures, caution should be taken when interpreting *prolonged looking times*. As in the existing literature on infants' change detection (e.g., Ross-Sheehy et al., 2003; Wang & Baillargeon, 2006; Wang & Mitroff, 2009), prolonged looking in the present experiments is taken as evidence for detecting a change from one picture to the next and the lack thereof as evidence for missing the change. However, there are at least two alternative interpretations worth considering. First, prolonged looking times may reflect infants' difficulties in updating their representation of the initial picture (e.g., Feigenson & Yamaguchi, 2009). It could be that changes conforming to prior knowledge are easily incorporated into the existing representation, whereas changes that violate prior knowledge require longer processing time. The updating interpretation can explain the present results that infants increased their looking times when changes disrupted scene gist or contradicted physical rules. However, it cannot explain why infants in the fast conditions of Experiments 1–3 also increased their looking times during the change trial when the influence of knowledge was minimized.

Second, it could be that infants had noticed all of the changes but looked longer only at the pictures that included a gist-incongruent item. According to this interpretation, prolonged looking would indicate infants' recognition of gist disruption within a single picture, rather than detecting the difference between the alternating pictures. For example, infants' prolonged looking might derive from their noticing a change that disrupted the gist, or their further processing of the gist-incongruent object, or both. It is certainly plausible that knowledge might have guided infants to notice local incongruity in a picture; however, this account cannot explain why the infants in the slow condition of Experiment 2 increased their looking times even though the post-change picture (where the shrub disappeared and was filled in by the exterior wall of the house) by itself did not present any incongruity. As another alternative, infants' prolonged looking times may be driven by the gist-incongruent item, the change across pictures, or both. Future research can further tease apart the underlying mechanisms by using a single picture that contains a gist-incongruent item (thus removing the change across pictures) and test whether prolonged looking is observed in infants' response to the picture.

Whatever the mechanism may be, the present results still provide converging evidence to support our hypothesis that at 15 months of age, infants apply both physical and scene knowledge when representing everyday scenes. In situations when infants cannot use relevant knowledge, they resort to perception-based processes and readily detect changes that are perceptually salient.

6.1. Infants' scene knowledge

In their everyday experience, infants encounter various types of rules when they observe or act upon the physical world. Research on cognitive development has shown that infants are sensitive to statistical rules (Denison & Xu, 2010a, 2010b; Xu & Denison, 2009). With respect to scene knowledge, expectations about what elements coexist in the same scene may derive from repeated exposure to the scene and the strength of associations among the items. For example, after seeing a toaster in the kitchen in many houses, we would expect to find a toaster in the kitchen rather than in the dining room when we visit another house. Information about objects and scenes could also come from observing other people's interactions with the environment. For example, an infant might learn about an object's proper placement when seeing the mother express surprise or discontent when she notices an improperly placed object, such as food in the bathroom. It seems likely that with these multiple sources of information, infants by 15 months of age already develop sets of expectations about common elements in various types of scenes.

Although we have used the term *knowledge* throughout this paper, it is important to note that it remains an open question whether infants do share with adults the same level of explicit knowledge or understanding of scene contexts. An implicit awareness that *something is out of place* would have sufficed to help infants detect gist-disrupting changes (see Richmond & Nelson, 2009 for further discussion on graded relational representations). Research on scene processing has shown that adults can quickly grasp the meaning of a scene without an elaborated processing of detailed perceptual information (e.g., Joubert et al., 2007; Rensink, 2000). Namely, an abstract overall meaning of a scene can be gleaned without explicitly recognizing its constituents. The existing research suggests that the infants in our experiments may be sensitive to scene irregularities, without explicitly knowing what the objects are or what purpose the objects may serve.

Because the present study did not directly test infants' explicit knowledge with the scenes, a logical extension would be to include measures of infants' experiences with the scenes (e.g., via additional parental surveys) or directly manipulate the level of experience (e.g., via training sessions). Findings that infants with different levels of scene expertise detect changes at different rates can further attest to the notion that scene knowledge plays a central role in organizing infants' visual attention and representation.

Another promising area for future research is the development of infants' sensitivity to scene gist. Scene gist can consist of perceptual and conceptual parts (Oliva, 2005). The perceptual scene gist, often based on color, spatial layout, sizes of scene elements, is formed very quickly in adults (within 120 ms, Biederman, 1981, as cited in Rensink, 2000; see also Oliva, 2005). For example, perceptual gist can help a viewer easily detect a change from natural scenes to an urban scene in the following way. Whereas natural scenes tend to encompass specific colors occurring in high frequency and occupying large proportions (e.g., forest, ocean, mountain), urban scenes tend to be more unpredictable in terms of color. Thus, based on color information alone, the viewer can perceive that a change has occurred without the active awareness of the identities of the pre- and post-change scenes. The perceptual gist is theorized to evoke the conceptual scene gist (see e.g., Oliva, 2005; Rensink, 2000), which includes recruiting and verifying relevant long-term scene knowledge that identifies the objects that are likely to occupy the scene; the viewer then use the activated scene knowledge to describe scene categories and recognize gist incongruity. By definition, long-term scene knowledge is involved as long as it is necessary to form a conceptual gist (i.e., to recognize the scene category), *without* the detail processing of individual objects. Thus, neither perceptual nor conceptual gist includes information about the identities of the objects present in the scene. In contrast, scene knowledge specifies the objects that are likely to be present. In other words, although these three levels of scene representation—perceptual gist, conceptual gist, and scene knowledge—offer an overall meaning for the scene, they vary in the viewer's explicit awareness of the scene elements. It is still unclear which of the above three is the primary mechanism underlying the present findings. Future research can directly examine whether infants possess long-term knowledge about scene categories, and if so, the developmental trajectory of their acquisition of scene knowledge.

Another area awaiting further investigation is the influence of presentation timing and cumulative exposure on infants' access to scene knowledge. In the present experiments, we limited infants' access by shortening the display duration. Although the pictures were displayed for only 500 ms at each appearance—too short for infants to access long-term memory—one could argue that infants might eventually accumulate enough exposure to the scene, over the course of the trial, to apply their knowledge (see Melcher, 2006 for a similar discussion on adults' visual processing). As demonstrated across multiple experiments here, infants' ability to detect the change varies as a function of presentation timing (i.e., slow versus fast conditions). Thus, the knowledge-based account we offered seems the most parsimonious explanation for the present results. Still, future research can peer into the fine-grained temporal aspects of scene representation by varying presentation timing while making the scene gist inaccessible with inverted images or jumbled pixels.

6.2. Continuity versus unchangeableness

The present research tests the contribution of basic object rules, specifically the rule that objects continue to exist over time and space, in processing everyday scenes. Even very young infants recognize the rule of object continuity (e.g., Spelke, 2000; Spelke et al., 1992, 1994; Wang & Baillargeon, 2008b). The results from Experiments 1 and 2 showed that when tracking changes in everyday scenes, the 15-month-old infants tended to miss a change when the scene gist was preserved, but the violation of object continuity enabled them to detect the change. These findings imply that physical knowledge may overpower infants' awareness of scene gist. Furthermore, they extend the three-system account of infants' physical reasoning by showing that prior knowledge affects not only infants' representation of physical events but also their representation of everyday scenes.

It is noteworthy that replacing items could have been perceived as violating one of the basic object rules, but it did not facilitate infants' change detection in Experiments 1, 3, and 4. For example, when the hydrant was replaced by the shrub, it could be perceived as if the hydrant continued to exist with different physical properties. If so, the change should contradict the rule of object unchangeableness—that objects maintain their physical properties over time (e.g., Baillargeon et al., 2009). However, the infants in the present research noticed the change when it violated the rule of continuity (Experiment 2) but not when it violated the rule of unchangeableness (Experiments 1, 3, and 4), even though infants detected both types of violations in the past research (e.g., Wang & Baillargeon, 2006; Wang & Mitroff, 2009; Wilcox et al., 2007). Compared to prior studies that have shown infants two to three objects moving on a stage, the present experiments used images that contained more items with higher visual complexity. The increased visual complexity could have made it difficult for the infants to detect the changes that violated the rule of unchangeableness, as it required infants to form a rich representation of the scene in order to keep track of the physical properties of the items involved. In contrast, changes that violated the rule of continuity remained highly detectable because even a crude representation of the scene would be sufficient for infants to recognize the omission of an item from the scene. Similar findings have been found with adults showing that object deletions were detected more readily than object replacements (e.g., Hollingworth & Henderson, 2000; Rensink, 2002).

6.3. Concluding remarks

The present research is among the first to bridge two areas of research on visual representation: infants' use of knowledge in event representation and adults' use of gist in scene representation. Extant research has shown that infants' prior knowledge affects their representation of physical events (Aguiar & Baillargeon, 2002, 2003; Baillargeon & Wang, 2002; Huettel & Needham, 2000; Wang & Baillargeon, 2006, 2008a, 2008b; Wang & Kohne, 2007; Wang & Mitroff, 2009; Wang et al., 2004; Wang et al., 2005; Wilcox et al., 2007). However, studies in this area utilized primarily staged objects and rarely complex real-world stimuli. The present research strengthens this literature by showing that infants also use prior knowledge in their representation of everyday scenes. Specifically, both physical knowledge and sensitivity to gist congruity seem to be operative as infants process real-world scenes. To this end, the present research broadens the existing literature on scene gist and real-world scene perception, which has been carried out extensively with adults and seldom with infants. Although further investigation on the development of scene knowledge is still needed, the present findings make it clear that scene gist plays an important role in helping infants track changes and maintain a coherent representation of the world.

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References

Aguiar, A., & Baillargeon, R. (1999). 2.5-month-old infants' reasoning about when objects should and should not be occluded. *Cognitive Psychology, 39*, 116–157. 10.1006 /cogp.1999.0717.

Aguiar, A., & Baillargeon, R. (2002). Developments in young infants' reasoning about occluded objects. *Cognitive Psychology, 45*, 267–336. http://dx.doi.org/10.1016/S0010-0285(02)00005-1.

Aguiar, A., & Baillargeon, R. (2003). Preservatives responding in a violation-of-expectation task in 6.5-month-old infants. *Cognition, 88*, 277–316. http://dx.doi.org/10.1016/S0010-0277(03)00044-1.

Atkinson, J. (1998). The 'where and what' or 'who and how' of visual development. In F. Simion & G. Butterworth (Eds.), *The development of sensory, motor and cognitive capacities in early infancy: From perception to cognition* (pp. 3–24). Hove, England: Psychology Press/Erlbaum (UK) Taylor & Francis.

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

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: Oxford University Press.

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

Baillargeon, R., & Wang, S. (2002). Event categorization in infancy. *Trends in Cognitive Sciences, 6*, 85–93. http://dx.doi.org/10.1016/S1364-6613(00)01836-2.

Beck, M. R., & Levin, D. T. (2003). The role of representation volatility in recognizing pre- and post-change objects. *Perception & Psychophysics, 65*, 458–468.

Biederman, I. (1972). Perceiving real-world scenes. *Science, 177*, 77–80. http://dx.doi.org/10.1126/science.177.4043.77.

Biederman, I., Glass, A. L., & Stacy, E. W. Jr., (1973). Searching for objects in real-world scenes. *Journal of Experimental Psychology, 97*, 22–27. http://dx.doi.org/10.1037/h0033776.

Bornstein, M. H., Mash, C., & Arterberry, M. E. (2010). Young infants' eye movements over "natural" scenes and "experimental" scenes. *Infant Behavior & Development, 34*, 206–210. http://dx.doi.org/10.1016/j.infbeh.2010.12.010.

Bornstein, M. H., Mash, C., & Arterberry, M. E. (2011). Perception of object–context relations: Eye-movement analyses in infants and adults. *Developmental Psychology, 47*, 364–375. http://dx.doi.org/10.1037/a0021059.

Cheries, E. W., Wynn, K., & Scholl, B. J. (2006). Interrupting infants' persisting object representations: An object-based limit? *Developmental Science, 9*, F50–F58. http://dx.doi.org/10.1111/j.1467-7687.2006.00521.x.

Conover, W. J. (1980). *Practical nonparametric statistics* (2nd ed.). New York, NY: Wiley & Sons Inc.

Csibra, G., Gergely, G., Biro, S., Koos, O., & Brockbank, M. (1999). Goal attribution without agency cues: The perception of "pure reason" in infancy. *Cognition, 72*, 237–267. http://dx.doi.org/10.1016/S0010-0277(99)00039-6.

Davenport, J. L., & Potter, M. C. (2004). Scene consistency in object and background perception. *Psychological Science, 15*, 559–564. http://dx.doi.org.oca.ucsc.edu/10.1111/j.0956-7976.2004.00719.x.

Denison, S., & Xu, F. (2010a). Integrating physical constraints in statistical inference by 11-month-old infants. *Cognitive Science: A Multidisciplinary Journal, 34*, 885–908. http://dx.doi.org/10.1111/j.1551-6709.2010.01111.x.

Denison, S., & Xu, F. (2010b). Twelve- to 14-month-old infants can predict single-event probability with large set sizes. *Developmental Science, 13*, 798–803. http://dx.doi.org/10.1111/j.1467-7687.2009.00943.x.

Dueker, G. L., Modi, A., & Needham, A. (2003). 4.5-month-old infants' learning, retention and use of object boundary information. *Infant Behavior & Development, 26*, 588–605. http://dx.doi.org/10.1016/j.infbeh.2003.05.002.

Dueker, G. L., & Needham, A. (2005). Infants' object category formation and use: Real-world context effects on category use in object processing. *Visual Cognition, 12*, 1177–1198. http://dx.doi.org/10.1080/13506280444000706.

Feigenson, L., & Yamaguchi, M. (2009). Limits on infants' ability to dynamically update object representations. *Infancy, 14*, 244–262. http://dx.doi.org/10.1080/15250000802707096.

Gergely, G., Nadasdy, Z., Csibra, G., & Biro, S. (1995). Taking the intentional stance at 12 months of age. *Cognition, 56*, 165–193. http://dx.doi.org/10.1016/0010-0277(95)00661-H.

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. http://dx.doi.org/10.1037/0096-1523.29.2.388.

Hollingworth, A. (2006). Visual memory for natural scenes: Evidence from change detection and visual search. *Visual Cognition. Special Issue: Visual search and attention, 14*, 781–807. http://dx.doi.org/10.1080/13506280500193818.

Hollingworth, A., & Henderson, J. M. (2000). Semantic informativeness mediates the detection of changes in natural scenes. *Visual Cognition, 7*, 213–235. http://dx.doi.org/10.1080/135062800394775.

Hudson, J. A., Fivush, R., & Kuebli, J. (1992). Scripts and episodes: The development of event memory. *Applied Cognitive Psychology, 6*, 483–505.

Hudson, J. A., & Nelson, K. (1986). Repeated encounters of a similar kind: Effects of familiarity on children's autobiographic memory. *Cognitive Development, 1*, 253–271.

Hudson, J. A., Shapiro, L. R., & Sosa, B. B. (1995). Planning in the real world: Preschool children's scripts and plans for familiar events. *Child Development, 66*, 984–998.

Huettel, S. A., & Needham, A. (2000). Effects of balance relations between objects on infants' object segregation. *Developmental Science, 3*, 415–427. http://dx.doi.org/10.1111/1467-7687.00136.

Joubert, O. R., Rousselet, G. A., Fize, D., & Fabre-Thorpe, M. (2007). Processing scene context: Fast categorization and object interference. *Vision Research, 47*, 3286–3297. http://dx.doi.org/10.1016/j.visres.2007.09.013.

Levin, D. T., & Simons, D. J. (1997). Failure to detect changes to attended objects in motion pictures. *Psychonomic Bulletin and Review, 4*, 501–506.

Luo, Y., & Baillargeon, R. (2005). When the ordinary seems unexpected: Evidence for incremental physical knowledge in young infants. *Cognition, 95*, 297–328. http://dx.doi.org/10.1016/j.cognition.2004.01.010.

Melcher, D. (2006). Accumulation and persistence of memory for natural scenes. *Journal of Vision, 6*, 8–17. http://dx.doi.org/10.1167/6.1.2.

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.

Needham, A., Cantlon, J. F., & Ormsbee Holley, S. M. (2006). Infants' use of category knowledge and object attributes when segregating objects at 8.5 months of age. *Cognitive Psychology, 53*, 345–360. http://dx.doi.org/10.1016/j.cogpsych.2006.05.003.

Nguyen, S. P. (2012). Inductive selectivity in children's cross-classified concepts. *Child Development, 83*, 1748–1761. http://dx.doi.org/10.1111/j.1467-8624.2012.01812.x.

Nijboer, T. C. W., Kanai, R., de Haan, E. H. F., & van der Smagt, M. J. (2008). Recognising the forest, but not the trees: An effect of colour on scene perception and recognition. *Consciousness and Cognition: An International Journal, 17*, 741–752. http://dx.doi.org/10.1016/j.concog.2007.07.008.

O'Regan, J. K., Rensink, R. A., & Clark, J. J. (1999). Change-blindness as a result of 'mudsplashes'. *Nature, 398*, 34.

Oakes, L. M., Messenger, I. M., Ross-Sheehy, S., & Luck, S. J. (2009). New evidence for rapid development of colour-location binding in infants' visual short-term memory. *Visual Cognition, 17*, 67–82. http://dx.doi.org/10.1080/13506280802151480.

Oakes, L. M., Ross-Sheehy, S., & Luck, S. J. (2006). Rapid development of feature binding in visual short-term memory. *Psychological Science, 17*, 781–787. http://dx.doi.org/10.1111/j.1467-9280.2006.01782.x.

Oliva, A. (2005). Gist of the scene. In L. Itti, G. Rees, & J. K. Tsotsos (Eds.), *The encyclopedia of neurobiology of attention* (pp. 251–256). San Diego, CA: Elsevier. doi:10.1016/B978-012375731-9/50045-8.

Onishi, K. H., Baillargeon, R., & Leslie, A. M. (2007). 15-month-old infants detect violations in pretend scenarios. *Acta Psychologica, 124*, 106–128. http://dx.doi.org/10.1016/j.actpsy.2006.09.009.

Otgaar, H., Candel, I., Scoboria, A., & Merckelbach, H. (2010). Script knowledge enhances the development of children's false memories. *Acta Psychologica, 133*, 57–63. http://dx.doi.org/10.1016/j.actpsy.2009.09.002.

Rensink, R. A. (2000). The dynamic representation of scenes. *Visual Cognition. Special Issue: Change blindness and visual memory, 7*, 17–42. http://dx.doi.org/10.1080/135062800394667.

Rensink, R. A. (2002). Change detection. *Annual Review of Psychology, 53*, 245–277. http://dx.doi.org/10.1146/annurev.psych.53.100901.135125.

Richmond, J., & Nelson, C. A. (2009). Relational memory during infancy: Evidence from eye tracking. *Developmental Science, 12*, 549–556. http://dx.doi.org/10.1111/j.1467-7687.2009.00795.x.

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. http://dx.doi.org/10.1046/j.1467-8624.2003.00639.x.

Ross-Sheehy, S., Oakes, L. M., & Luck, S. J. (2011). Exogenous attention influences visual short-term memory in infants. *Developmental Science, 14*, 490–501. http://dx.doi.org/10.1111/j.1467-7687.2010.00992.x.
Sampanes, A. C., Tseng, P., & Bridgeman, B. (2008). The role of gist in scene recognition. *Vision Research, 48*, 2275–2283. http://dx.doi.org/10.1016/j.visres.2008.07.011.
Simons, D. J. (2000). Current approaches to change blindness. *Visual Cognition, 7*, 1–15. http://dx.doi.org/10.1080/135062800394658.
Simons, D. J., & Ambinder, M. (2005). Change blindness: Theory and consequences. *Current Directions in Psychological Science, 14*, 44–48. http://dx.doi.org/10.1111/j.0963-7214.2005.00332.x.
Spelke, E. S. (2000). Core knowledge. *American Psychologist, 55*, 1233–1243. 10.1037 /0003-066X.55.11.1233.
Spelke, E. S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review, 99*, 605–632. http://dx.doi.org/10.1037/0033-295X.99.4.605.
Spelke, E. S., Katz, G., Purcell, S. E., Ehrlich, S. M., & Breinlinger, K. (1994). Early knowledge of object motion: Continuity and inertia. *Cognition, 51*, 131–176. http://dx.doi.org/10.1016/0010-0277 (94)90013-2.
Wang, S. (2011). Priming 4.5-month-old infants to use height information by enhancing retrieval. *Developmental Psychology, 47*, 26–38. http://dx.doi.org/10.1037/a0021060.
Wang, S., & Baillargeon, R. (2006). Infants' physical knowledge affects their change detection. *Developmental Science, 9*, 173–181. http://dx.doi.org/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. http://dx.doi.org/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. http://dx.doi.org/10.1016/j.tics.2007.10.012.
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. http://dx.doi.org/10.1016/j.cognition.2003.09.012.
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. http://dx.doi.org/10.1016/j.cognition.2002.11.001.
Wang, S., & Kohne, L. (2007). Visual experience enhances infants' use of task-relevant information in an action task. *Developmental Psychology, 43*, 1513–1522. 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. http://dx.doi.org/10.1111/j.1467-7687.2008.00800.
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*, 163–173.
Wilcox, T., Woods, R., Chapa, C., & McCurry, S. (2007). Multisensory exploration and object individuation in infancy. *Developmental Psychology, 43*, 479–495. http://dx.doi.org/10.1037/0012 -1649.43.2.479.
Xu, F., & Denison, S. (2009). Statistical inference and sensitivity to sampling in 11-month-old infants. *Cognition, 112*, 97–104. http://dx.doi.org/10.1016/j.cognition.2009.04.006.