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What Do Infants Remember When They Forget? Location and Identity in 6-Month-Olds' Memory for Objects

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Abstract

What does an infant remember about a forgotten object? Although at age 6 months, infants can keep track of up to three hidden objects, they can remember the featural identity of only one. When infants forget the identity of an object, do they forget the object entirely, or do they retain an inkling of it? In a looking-time study, we familiarized 6-month-olds with a disk and a triangle placed on opposite sides of a stage. During test trials, we hid the objects one at a time behind different screens, and after hiding the second object, we removed the screen where the first object had been hidden. Infants then saw the expected object, the unexpected other object, or the empty stage. Bayes factor analysis showed that although the infants did not notice when the object changed shape, they were surprised when it vanished. This finding indicates that infants can represent an object without its features.

Keywords

cognitive development, visual memory, infant development

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Infants have robust expectations about the properties and behavior of physical objects. In the first year of life, infants expect objects to be solid, bounded in space, and cohesive (e.g., Baillargeon, 1991; Spelke, 1990) and to continue to exist with the same properties after passing from view (e.g., Baillargeon, Spelke, & Wasserman, 1985). Infants can also keep track of more than one hidden object at a time (Wynn, 1992). However, despite understanding some physical laws governing objects, infants have a limited ability to recall objects in detail once those objects are out of view.

Adults can keep track of about four objects simultaneously (Scholl & Pylyshyn, 1999); infants have a limit of about three, and this limit does not increase between 5 and 12 months of age (Feigenson & Carey, 2003; see also Chen & Leslie, 2009, and Feigenson, 2007). However, if we examine precisely what infants can recall about the objects they are keeping track of, we find that their memory appears to be limited to even fewer than three objects (F. Xu & Carey, 1996). Young infants can recall identifying properties for only a subset of objects in a display in which the objects are hidden. When required to remember two objects hidden one after the other in different locations, infants at 9 months of age recall the shapes of both objects but not their colors (Káldy & Leslie, 2003). Six-and-a-half-month-olds are even more limited; they can recall the shape of only the most recently hidden object (Káldy & Leslie, 2005).

What happened to infants' memory for the second shape in the latter case? One clue may be that objects are individuated more readily by their spatiotemporal locations than by their identifying features, such as color and shape (Leslie, Xu, Tremoulet, & Scholl, 1998; Spelke, Breinlinger, Macomber, & Jacobson, 1992). Mareschal and Johnson (2003) found that 4-month-old infants had difficulty recalling identifying information about an object other than its location, unless the object's featural information pertained to an action relevant to the object. Perhaps the integration of infant brain systems underlying "what" information and "where/how" information proceeds relatively slowly (Káldy & Sigala, 2004). When object representations lack identifying information, infants may remember the "where" of two objects but the "what" (e.g., shape, color) of only one.

What happens in infants' memory when they retain the identity of only one of the objects in a pair they are tracking, but not the identity of the other? Is that object entirely forgotten, or does

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some inkling of its presence remain in memory? There are at least two possibilities. If the presence of the object is forgotten along with its identity, infants will have no expectations about the contents of the location where the object was placed and thus will not be surprised if the unremembered object has completely disappeared. Alternatively, if 6-month-old memory span is actually large enough to retain more objects than features, infants may retain the identity of only one hidden object per scene but maintain a representation of the second object without its unique identifying features. Consequently, despite not remembering its shape (or color), infants will nevertheless be surprised if the unremembered object has vanished.

In the study reported here, we asked what 6-month-olds remember when they forget the identity of an object. We used the looking-time task of Káldy and Leslie (2003), which requires infants to keep track of both spatiotemporal and featural properties of objects. We hid objects one at a time in distinct locations, each behind its own screen. Then we raised one of the screens, revealing either the object hidden there originally, the object that had been hidden in the other location, or no object at all. This method allowed us to test infants' memory for any object in a multiple-object array. For example, infants' memory could be tested for the object that was hidden last (and thus easier to recall) or for the object that was hidden first (thus harder to recall; for why this methodology tests infant working memory, see Leslie & Káldy, 2007). We were interested in what infants remember about the contents of the harder-to-recall location, so we removed the screen covering the first-hidden object.

Method

Subjects

Subjects were 36 healthy full-term infants (20 females, 16 males) between 21.6 and 31.4 weeks of age (*M* = 26 weeks, *SD* = 3 weeks). Six infants of the original sample of 42 were excluded because of fussiness (3 infants), experimenter error (2 infants), and parental interference (1 infant). Infants were recruited from the central New Jersey area by calling lists of new parents, and participating families received a reimbursement and a small gift. Infants were assigned evenly to three conditions (*n* = 12 per condition).

Design

Infants were familiarized with two objects, a disk and a triangle, placed on an empty stage. The side of the stage on which each object was placed alternated from trial to trial, so that each object appeared equally often in both locations, with first placement counterbalanced across subjects. Following familiarization, the experimenter placed two screens on the stage, one on each side. Continuing the alternating-side placement, the experimenter separately placed the two objects on the stage, one in front of each screen, and then placed them one at a time behind their respective screens. The experimenter then removed the screen in front of the first hidden (harder-to-remember) object, revealing one of three possible outcomes: the object originally hidden there (control condition), the object that had been hidden behind the other screen (swap condition), or no object (vanish condition; Fig. 1).

Materials and procedure

Infants sat on their caregiver's lap at a distance of 91.5 cm from a 95- × 48- × 56-cm white foam-core stage. Each infant

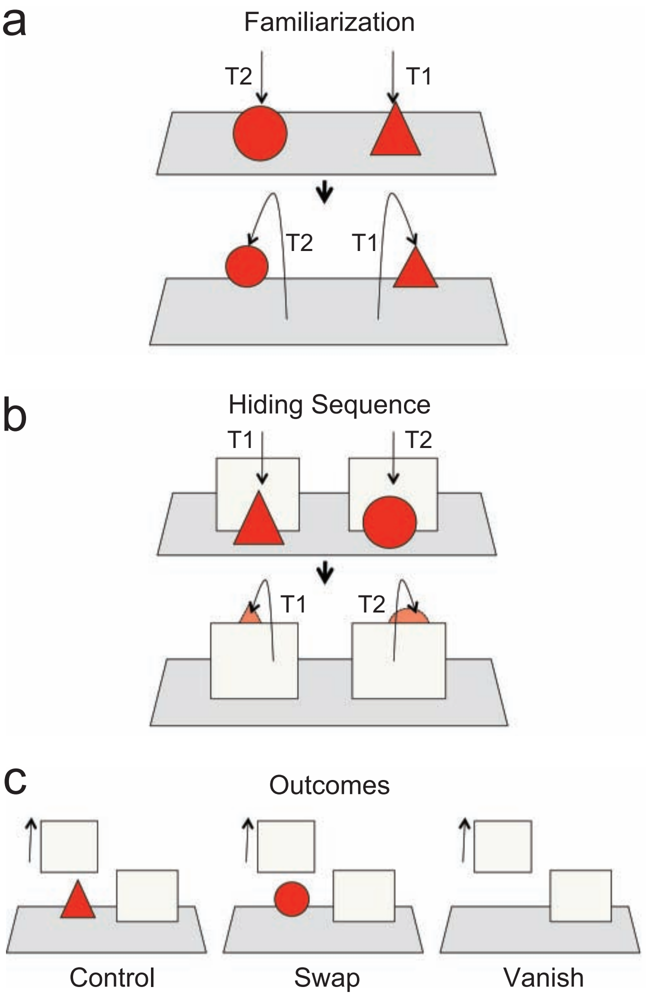

Fig. 1. Example familiarization- and test-trial sequences and possible outcomes of test trials. On each familiarization trial (a), two objects—a disk and a triangle—were placed one at a time on opposite sides on the front of a stage. The two objects were then moved sequentially to the back of the stage. (In these illustrations, the first object to be moved is designated T1, and the second object is designated T2.) On each test trial (b), objects were moved in the same manner as on familiarization trials, but screens were placed in the middle of the stage so that the objects would be hidden when they were moved to the back. After this hiding sequence, the screen in front of the first-hidden object was removed (c) to reveal one of three outcomes: the object that was hidden first (the harder-to-recall object; control condition), the object that had been hidden behind the other screen (the swap condition), or no object (the vanish condition). Subjects in all groups viewed the same familiarization trials, but each of the three groups saw only one of the three outcome conditions on the test trials.

was tested separately. Stimuli were two wooden shapes, a disk (diameter = 10.15 cm) and a triangle (base = 10.15 cm, height = 11.4 cm), both painted red. The shapes were placed on the front of the stage about 99 cm from the infant (6° of visual angle), then moved to the back of the stage about 138 cm from the infant (4° of visual angle). During test trials, shapes were hidden behind two dark gray foam-core screens (17.75 × 17.75 cm) placed about 133 cm from the infant. Between trials, the experimenter raised a yellow curtain to cover the stage.

At the start of the experiment, the experimenter drew the infant's attention to the front and back corners and to the midpoints of the front and back of the stage by jingling bells she wore around her wrist. A hidden observer watched each infant's face on a monitor during this process to get a sense of each infant's eye positioning relative to the stage.

In each of four familiarization trials, which were synchronized to a metronome, the experimenter placed the disk and the triangle one at a time on either side of the front of the stage and after 4 s moved these objects individually to the back of the stage in the same order in which they were initially presented. After 8 s, the experimenter raised a curtain covering the viewing area and ended the trial. The order in which the shapes were presented and the position of each shape were alternated across trials.

Before the test phase, the experimenter asked caregivers to close their eyes. Each of four test trials began with two screens being placed toward the back of the stage. The experimenter then placed the objects at the front of the stage (the order and position of each shape were again alternated across trials). After 4 s, the experimenter hid the objects one at a time behind their respective screens. The experimenter then drew the infants' attention to the screen that occluded the first hidden (harder-to-remember) object by jingling bells around her wrist. She then raised that screen to reveal one of the three outcomes (Fig. 1).

An observer blind to condition scored looking times using a live video feed showing the infants' head and shoulders. When the experimenter removed the screen, she signaled the observer to begin timing. Custom software recorded all timings. When the infant looked away for 2 s, the stage lights were extinguished, and the experimenter raised the curtain. Two additional observers blind to condition later rescored looking times from videotape. Interobserver reliability, computed as the mean distance between on-line and off-line observer's scores divided by the mean of the on-line observer's scores, was always greater than 90% across trials; therefore, we used the on-line observer's scores.

Results

Significance-testing analyses

One test trial was excluded because of experimenter error, thus analyses were based on 143 trials total. Because of right skew, all data were log transformed (Hays, 1994); this is a common procedure when analyzing infant looking-time data (e.g., Leslie & Chen, 2007; Spelke, Kestenbaum, Simons, & Wein, 1995). We analyzed log looking times in a 3 (condition: swap, vanish, control) × 4 (trial: 1–4) repeated measures analysis of variance (ANOVA). There was no effect of trial, $F(3, 93) < 1.0$, and no Trial × Condition interaction, $F(6, 93) = 1.24$, $p = .29$, $\eta^2 = .074$. A significant effect of condition was found, $F(2, 31) = 3.54$, $p = .041$, $\eta^2 = .186$. Further analyses dropped trial as a factor. Figure 2 shows raw and log-transformed looking times averaged over all test trials and for the first test trial only for each condition.

Averaged log looking times for the vanish and the swap conditions were compared separately with averaged log looking times for the control condition using a Dunnett's *t* test: Log looking times in the vanish condition were significantly longer than log looking times in the control condition ($p = .021$, two-tailed), but log looking times in the swap condition were not ($p = .39$, two-tailed). These findings suggest that infants expected an object to be revealed but were unable to recall the shape of that object.

The largest effects for infant looking-time data typically occur on the first test trial. In accordance with this expectation, an ANOVA on log looking times for only the first test trial showed a significant effect of condition, $F(2, 33) = 4.076$, $p = .026$, $\eta^2 = .198$. A Dunnett's *t* test comparing results from the swap condition with results from the control condition showed no significant difference between the two ($p = .67$, two-tailed), replicating the findings of Káldy and Leslie (2005). Planned comparison of results from the vanish and the swap conditions showed longer log looking times for the vanish outcome, $t(22) = 2.256$, $p = .034$, two-tailed. These results were confirmed nonparametrically—vanish condition versus swap condition: Mann-Whitney $U = 36.5$, $z = -2.05$, $p = .04$, two-tailed; swap condition versus control condition: Mann-Whitney $U = 58$, $z = -0.808$, n.s.

Bayes factor analyses

Figure 3 provides a visualization of our looking-time data. The plots show theoretical distributions of the data obtained by estimating the maximally likely mean and standard deviation given the data (the mle function in MATLAB, The MathWorks, Natick, MA). These distributions are plotted as cumulative Gaussian probability distributions in Figure 3, along with the observed data.

We used these theoretical distributions to quantify the likelihood that the same or different processes generated the data. Standard significance-testing statistics allow us to reject the null hypothesis only at a given confidence level; but they do not allow us to infer how likely it is that the null hypothesis is actually true (e.g., Hays, 1994). However, we are just as interested in whether infants actually forgot the shape of the object as we are in whether they remembered its existence. Showing forgetting requires us to prove the null hypothesis—that there is no difference in looking times between the swap and control

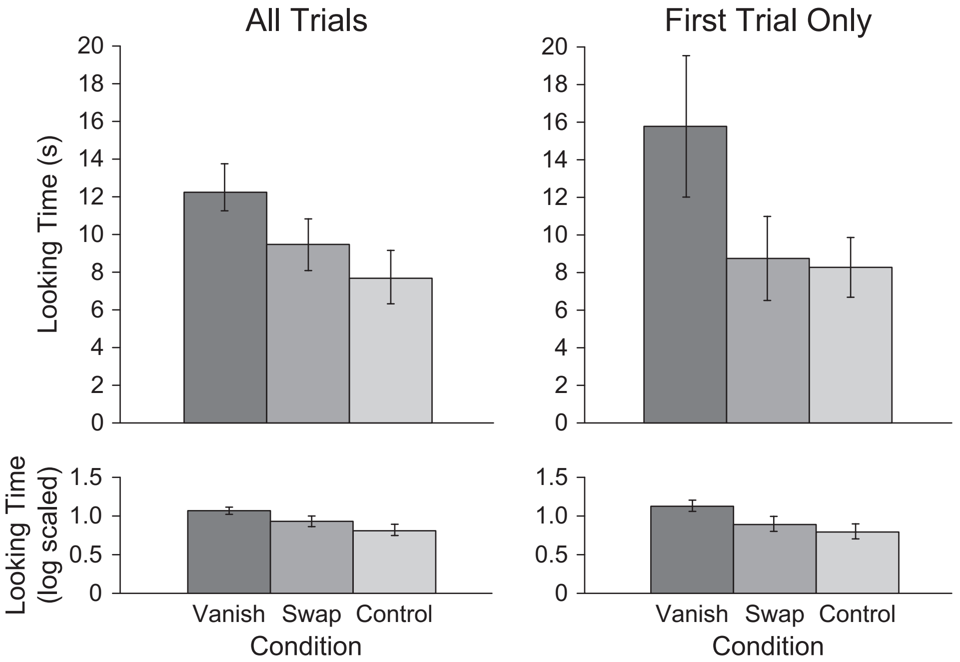

Fig. 2. Looking-time data averaged across all test trials (left panels) and for the first test trial only (right panels), as a function of condition. The top panels show raw data, and the bottom panels show log-transformed data. Error bars represent ±1 *SEM*.

groups. Further, it is useful to show that there is a robust difference between results for the vanish condition and for the swap and control conditions. Recent developments in Bayesian decision science make it easy to assess the extent to which available data favors either the null or the experimental hypothesis (Gallistel, 2009; Rouder, Speckman, Sun, Morey, & Iverson, 2009). Charles Gallistel at Rutgers University provides an Internet-based application to compute Bayes factors by comparing the theoretical distribution of control-group data with that of an experimental group and obtaining the odds that the same process generated both sets of data (http://cognitivegenetic.rutgers.edu/ptn/ptn_online/bf2.aspx).

Using this method to compare average log looking times in the control and swap conditions yielded odds of 2.44:1 in favor of the null hypothesis. Because Káldy and Leslie (2005) reported the same comparison, we combined the data from their study and our current study and recomputed the Bayes factor. This analysis yielded support for the null hypothesis with odds of 5.45:1 in favor of the null. In everyday terms, currently available data shows that the hypothesis that the infants forgot the shape of the first-hidden object is over 5 times more likely than the alternative hypothesis (H_1) that they noticed the first-hidden object had changed. By contrast, collapsing results from the swap and control conditions in the present study and comparing them with results from the vanish condition yielded odds of 7.4:1 in favor of H_1, namely, that infants in the vanish condition noticed that the object had disappeared. Combining swap and control data from the current study with analogous data from Káldy and Leslie (2005) and comparing this collapsed data with results from the vanish condition provided substantial evidence, with odds of 31.2:1, in favor of H_1.

Discussion

In the study reported here, we found that 6-month-olds were unable to recall the shape of the harder-to-remember of two objects, but these infants were surprised when that object disappeared completely. What happened to the memory of the "forgotten" object?

One possibility is that information held in working memory rapidly decays. However, a number of studies have found that infants maintain working memory representations of objects over much longer delays (e.g., Baillargeon & Graber, 1988; Káldy & Leslie, 2005; Luo, Baillargeon, Brueckner, & Munakata, 2003). Another possibility is that infant working memory has limited resolution (Awh, Barton, & Vogel, 2007; Y. Xu & Chun, 2006; Zhang & Luck, 2008). Under this account, working memory represents both objects, but only one representation carries sufficient detail to allow infants to notice a shape change. Infants are unable to discriminate the shape-memory signal of the harder-to-recall object from its revealed visible shape.

However, shape is a highly salient feature to which infants may be biased to attend. Wilcox, Haslup, and Boas (2010) showed that 4.5-month-old infants use shape but not color or pattern to individuate objects, but it is not until around 11 months of age that infants use all three of these features. In the current study, infants had a further incentive to attend to shape because only shape uniquely identified the objects. Further,

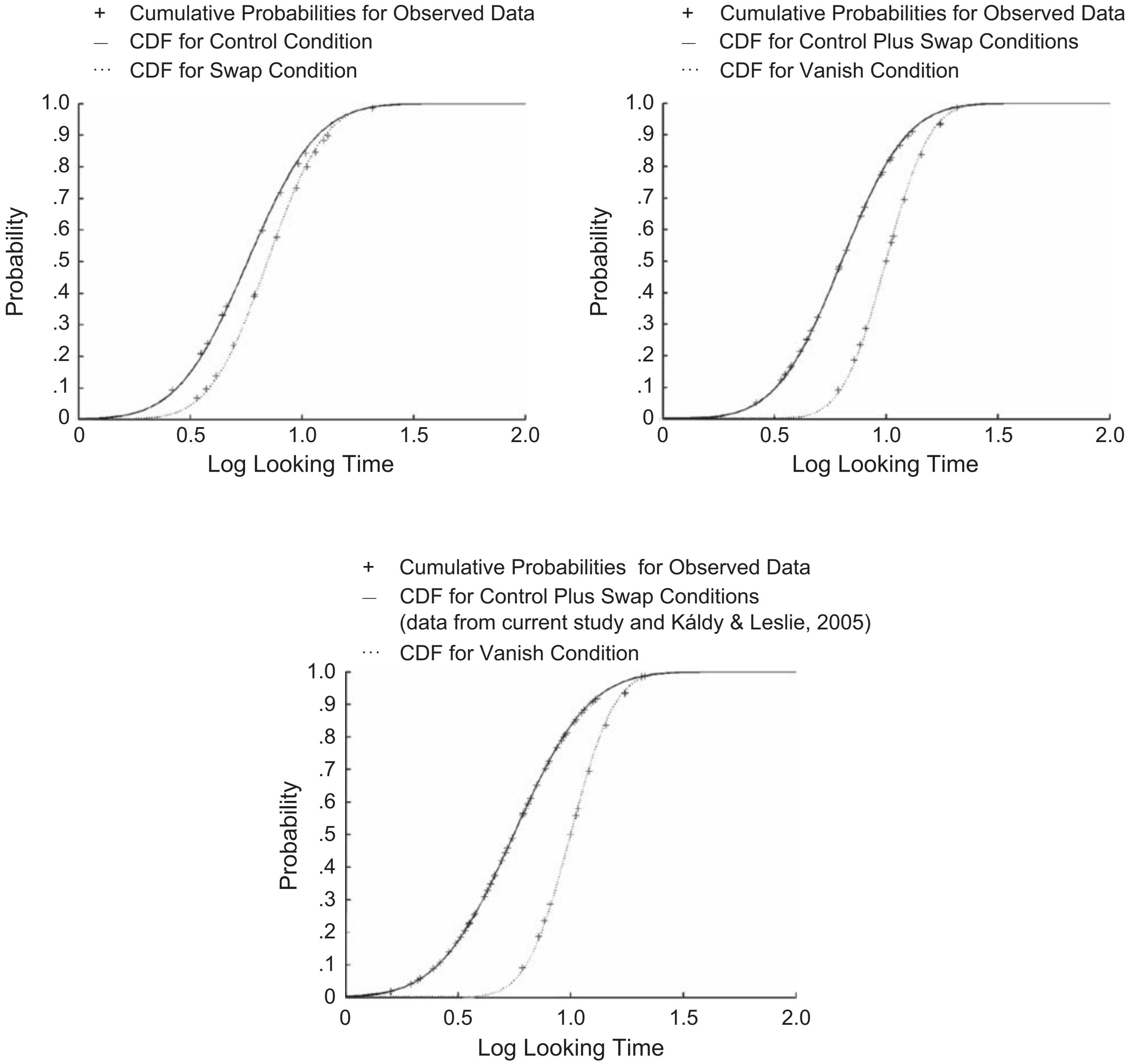

Fig. 3. Theoretical cumulative distribution functions (CDFs) showing probabilities for log looking times obtained by estimating the maximally likely parameters given the data. The graphs also show the cumulative probabilities of the log-looking-time scores that were observed. The top left panel shows results for the control and swap conditions separately. The top right panel shows results from the vanish condition and results collapsed across the control and swap conditions. The bottom panel shows results from the vanish condition and results collapsed across the control and swap conditions of the current study plus a previous study by Káldy and Leslie (2005).

infants detect even subtle differences in shape. Káldy and Blaser (2009) used a preferential first-looking paradigm with 6.5-month-olds to assess the relative transdimensional visual salience of shape-, color-, and luminance-defined stimuli. They found that a much smaller change in shape (such as adding a notch in the contour of a polygon) is required to produce preferential first looking to shape-defined stimuli compared with color- and luminance-defined stimuli. If the large shape change we used (disk to triangle) was insufficiently salient, this implies that memory resolution is so limited as to be essentially nonfunctional.

Still another possibility is that infants are using object indexes to keep track of individual objects as they move through locations, including in and out of occluded locations, but their ability to bind identities to those indexes and to maintain such bindings remains immature (Leslie et al., 1998; Wang & Baillargeon, 2008). In the current study, during the interval between when the first and the last objects were hidden, infants' attention was drawn away to a different location and hiding event. Káldy and Leslie (2005) suggested that successive hidings overwrite existing storage. Our present findings, though restricted to bottom-up visual features, suggest a different picture. Maintaining feature bindings across multiple occluded locations may require sustained attention, and because infants' underlying neural systems are immature (Kaufman, Csibra, & Johnson, 2003), successive hidings lead to loss of existing bindings.

Conclusion

When infants forget the shape of an object hidden in a location, all is not lost. Even though young infants forget the unique featural identity of the object, they maintain a representation of the object in a location and are surprised when it disappears completely. This suggests that infants' working memory supports an object representation that is featureless.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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