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A memory span of one? Object identification in 6.5-month-old infants

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Abstract

Infants' abilities to identify objects based on their perceptual features develop gradually during the first year and possibly beyond. Earlier we reported [Káldy, Z., & Leslie, A. M. (2003). Identification of objects in 9-month-old infants: Integrating 'what' and 'where' information. *Developmental Science*, *6*, 360–373] that infants at 9 months of age are able to use shape information to identify two objects and follow their spatiotemporal trajectories behind occlusion. On the other hand, another recent study suggests that infants at 4–5 months of age cannot identify objects by features and bind them to locations [Mareschal, D., & Johnson, M. H. (2003). The "what" and "where" of object representations in infancy. *Cognition*, *88*, 259–276]. In the current study, we investigated the developmental steps between these two benchmark ages by testing 6.5-month-old infants.

Experiment 1 and 2 adapted the paradigm used in our previous studies with 9-month-olds that involves two objects hidden sequentially behind separate occluders. This technique allows us to address object identification and to examine whether only one or both object identities are being tracked. Results of experiment 1 showed that 6.5-month-old infants could identify at least one of two objects based on shape and experiment 2 found that this ability holds for only one, the last object hidden.

We propose that at this age, infants' working memory capacity is limited to one occluded object if there is a second intervening hiding. If their attention is distracted by an intervening object during the memory maintenance period, the memory of the first object identity appears to be lost. Results of experiment 3 supported this hypothesis with a simpler one-screen setup. Finally, results of experiment 4 show that temporal decay of the memory trace (without an intervening hiding) by itself

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cannot explain the observed pattern of results. Taken together, our findings suggest that at six months of age infants can store but a single object representation with bound shape information, most likely in the ventral stream. The memory span of one may be due to immaturity of the neural structures underlying working memory such that intervening items overwrite the existing storage.
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1. Introduction

Research in the past two decades has revealed that human infants demonstrate significant competence in regard to the physical world early on. Infants assume that objects are solid, bounded, spatiotemporally unique entities (Baillargeon, 1986, 1987; Baillargeon, Spelke, & Wasserman, 1985; Spelke, 1988, 1994; Spelke, Breinlinger, Macomber, & Jacobson, 1992); they appreciate object numerosity (Wynn, 1992); and they recognize the causal roles of objects in actions (Leslie & Keeble, 1987). On the other hand, infants also show some remarkable limitations in using perceptual features to individuate and identify objects (Simon, Hespos, & Rochat, 1995; Tremoulet, Leslie, & Hall, 2000; Wilcox & Baillargeon, 1998; Xu & Carey, 1996). Here we investigate object identification in young, 6.5-month-old infants, at which age evidence for this ability is relatively sparse.

1.1. Individuation versus identification of objects

Leslie, Xu, Tremoulet, and Scholl (1998), drawing upon the literature on adult attention, introduced to infancy researchers a distinction between the *individuation* and *identification* of objects. Individuation refers to the detection of a novel object and the resulting establishment of an object representation (OR). Detection of further objects results in the establishment of additional OR's. Identification, on the other hand, requires the further step, following individuation, of entering information into an already established OR. Unless information is entered into, or 'bound' to, the OR, such information will not be available later for determining the identity of that object.

Gratch and his colleagues in the seventies were among the first to study object identification in infants (Gratch, 1976; LeCompte & Gratch, 1972; Saal, 1976). He highlighted the problem as "whether what we see now was different, similar or the same as what we once saw and, comparably, will be the same, similar or different from what we will see" (Gratch, 1976, p. 173). In a typical experiment, they would first hide a particular toy in a box and let the infant find it. After a few such trials, a trick followed: after hiding the original toy, as usual, infants when searching actually found a different toy in the box. The experimenters scored the infant's reactions to the new object (puzzlement, search) on an ordinal scale. In the Saal (1976) study, a complex featural difference was contrasted with a single featural (color) difference. She found that there is a noticeable change in infants' behavior between 6 and 9 month, regardless of the nature of the difference between the old and the new toy: 9-month-olds, but not 6-month-olds reacted with mild puzzlement.

Unfortunately, these early studies by Gratch and his colleagues had some methodological flaws. First, infants were not systematically familiarized to the features of the new toy before the trick, and because of this, they could have reacted simply to the novelty of the features as such rather than to a violation of object identity as such. In other words, infants might react to novelty at a level lower than the object representation (see Tremoulet et al., 2000 for further discussion). Secondly, measuring puzzlement and search as dependent variables in young infants likely underestimates their competence by neglecting other measures that may have revealed differences, notably, for the present purposes, looking-time measures. Indeed, Gratch remarks that "at younger ages [6 months], the infants would stare longer at the new toy than the old toy" (Gratch, 1976, p. 172), but does not consider this serious evidence.

More recently, there have been several studies of object identification using looking times measures (Káldy & Leslie, 2003; Mareschal & Johnson, 2003; Newcombe, Huttenlocher, & Learmonth, 1999; Tremoulet et al., 2000; Wilcox & Schweinle, 2002). We review these below.

1.2. The role of perceptual differences in identification

There is an important issue regarding perceptual features that is often neglected in the developmental literature. This is the fact that features may be recognized yet not retained in working memory for later processing. In other words, infants may be able to *discriminate* two objects without being able to *remember* what that difference was later on. Researchers often ignore this principle and choose particular featural differences based only on the criterion that they should be above absolute perceptual thresholds. However, this criterion in itself does not guarantee positive results in a paradigm that requires an infant to retain the knowledge of this difference over time.

Moreover, even if a particular experiment yields positive results—pointing to successful identification of objects—to what aspect of perceptual difference between the objects should this success be attributed? With a few exceptions (Káldy & Leslie, 2003; color differences: Saal, 1976; Santos, Sulkowski, Spaepen, & Hauser, 2002; Tremoulet et al., 2000; Wilcox, 1999), most studies in the infant object memory literature (Bonatti, Frot, Zangl, & Mehler, 2002; LeCompte & Gratch, 1972; Newcombe et al., 1999; Needham, 2001; Simon et al., 1995; Wilcox & Schweinle, 2002; Xu & Carey, 1996) have used complex featural differences that exist between more or less randomly chosen toys—differences which are difficult to quantify psychophysically. In these cases, it is often difficult, if not impossible, to generalize these results to other stimuli: Would the same pattern of results hold with two different choices of toys? Which perceptual feature dimension did the infants rely on, color, spatial frequency (texture), contrast or 3D shape? Without the exact knowledge of relative perceptual thresholds and discriminability, the best way to proceed is to use perceptually simple and carefully controlled stimuli. In the present study, as in Káldy and Leslie (2003); Tremoulet et al. (2000), target objects had simple geometrical shapes (triangles and circles) and both objects and other props were uniformly colored.

1.3. Age of onset of identification by feature and location

A few studies have recently looked at identification by feature and location in young infants. Newcombe et al. (1999) have shown that 5-month-old infants were able to encode object locations. However, the infants did not seem to be able to identify objects by feature. They looked longer when they saw a previously hidden object being dug out from a different location in a sandbox, but they did not react when the experimenter hid two different toys and then retrieved each of them from the wrong location (that is, where the other object was hidden). However, young infants probably have little prior experience with burying and retrieving objects in sand.

Another recent study by Mareschal and Johnson (2003) tested visual working memory capacities of even younger, 4-month-old infants. In an ingenuous design, they used two types of stimuli: faces and asterisks that were assumed to selectively activate the ventral ("what") visual stream, and manipulable toys that were chosen to selectively activate the dorsal ("where" or "how") visual stream. The experimental setup was very similar to Káldy and Leslie's (2003) paradigm: infants saw two objects hidden sequentially behind two separate screens. Infants in their experiments reacted to a featural violation with the first type of stimuli (faces and asterisks) and to a location violation with the second type of stimuli (manipulable toys), but not vice versa; in neither case did they react to a violation of the features bound to particular locations. Mareschal and Johnson interpreted these findings as showing the early segregation of the dorsal and the ventral visual streams.

Leslie et al. (1998) proposed that dorsal and ventral systems of object perception were segregated early in infancy, becoming integrated only after 10 months of age, and Mareschal and Johnson's results are consistent with this picture. However two cautionary points should be made. First, studying dorsal representations is especially difficult, because their lifetime is only a few seconds, and they only function during that period when they are required for the online control of actions. Hu and Goodale (2000) found that in adults, this functional period is less than 5 s, and if the delay between perception and action is longer than that, then actions will be driven by ventral representations.[1] Even more importantly, a recent paper by Westwood and Goodale (2003) points out that adult dorsal representations are engaged for the control of action only *after* an action is cued, and only if the target remains visible. In Mareschal and Johnson's study, the first hidden object was covered for over 10 s, while the second object was hidden for about 5 s. Therefore, it is doubtful that the images of manipulable toys could have activated dorsal representations in infants.

Second, putting aside timing concerns, Mareschal and Johnson's study omitted an important condition for their argument. Whereas there is independent evidence to support the ventral nature of face perception, it remains to be shown that the asterisk stimuli were processed ventrally by their infants. Faces may be a special case, but the asterisks might have looked like toys to the infants and they may have represented them as manipulable. To rule this out, one group of infants might have played with asterisk-shaped objects along with the other toys before the test. Only if the results for these infants show that they remembered the location, but not the features of the asterisks, could we be sure that the original non-manipulated asterisk infants in fact relied on ventral representations.

[1] Comparative studies of infant and adult processing speed are rare, but one recent study suggests that response latencies in the visual system in infants are longer than in adults (Crognale, 2002).

The question of the development of ventral-dorsal integration remains open despite these suggestive findings.

In a study by Wilcox and Schweinle (2002), 5.5-month-old infants saw a two-screen display, where one object (an egg) disappeared behind one screen, and another object (a column) appeared from behind an adjacent screen. The screens were then dropped, and either an egg or a column was revealed behind the first screen. Infants reacted to the unexpected identity in this paradigm. However, they did not look longer in a modified experimental scenario when a third object (a triangle) was revealed behind the first screen. Taken together, these results showed that infants remembered that “there were two different objects”, but not that “there was an egg and a column”. Infants at this age then do not appear to bind sufficient information to make a positive identification possible.

We have been studying how and when infants become capable of identifying objects based on different featural dimensions (e.g. by shape). In our usual paradigm, we familiarize infants with a triangle and a disk, displaying each, one at a time, drawn from and returned behind a screen (That is, the two objects are never presented simultaneously). Then in the test (unexpected condition), the screen is removed to reveal either two disks or two triangles. With this paradigm, it is not until 12 months of age that the first evidence for identification of objects by shape *with sequential presentation* has been obtained (Tremoulet et al., 2000). In this study, 12-month-old infants looked significantly longer at the two objects with identical shapes than in a control condition where the screen revealed the expected disk and triangle. This implies that these infants expected not simply two things, but expected exactly one of the things to be a disk and the other to be a triangle. However, it is important to point out that the Tremoulet et al. study has also demonstrated that identification capabilities at this age are still limited: infants at the same age could not identify objects by color in the same paradigm.

Káldy and Leslie (2003) presented evidence using a two-screen paradigm that 9-month-old infants are able to identify objects by shape and location. Infants were first familiarized to two objects, a triangle and a disk, that appeared on alternate sides from trial to trial. In test trials, they were hidden sequentially behind two screens. Nine-month-old infants looked significantly longer when both screens were removed to reveal the same two objects in switched positions. Because the sidedness of the shapes was swapped from trial to trial, the infants were forced to track the locations of the objects on a trial-to-trial basis. Only then could they notice whether the shapes were in the wrong location on a given trial. This shows infants bound shape information to the correct object representations respectively and did not simply associate shapes with scene locations more generally. They are therefore tracking *what* object went *where*.

1.4. The beauty of two screens

In multiple object experiments, the question of whether infants attend to all of the objects or just to one of them is seldom addressed. This is particularly relevant in identification experiments. For example, when the identities of two objects hidden behind a single screen both change, infants might look longer because they notice the change in only one of the objects—the one they happened to be tracking. When the identity of only one of two objects is changed, infants might look longer because they were tracking both objects but also because each infant was tracking only one of the objects. When the screen is removed, half the infants look longer because about half were tracking the object that happened to change. Sub-sampling by infants is a pressing problem if one is interested in the question of how many object identities infants at a given age can track. As far as we can see, there is no way to address the sub-sampling issue using a single screen.

Previous studies of identification, reviewed above, have not addressed the sub-sampling issue. Their results therefore only show that infants can identify *at least* one of two objects; but they do not show explicitly that infants identify two objects simultaneously. The exception to this is Káldy and Leslie (2003) who compared results in a two-screen experiment where both screens were removed and both object identities were changed with a new experiment. In this new experiment only one of the screens was removed, namely, the one that hid the *first*-hidden object. For example, if the red triangle had moved behind the left screen and then the blue disk had moved behind the right screen, only the left screen would be removed. The features of this object have to be retained for a longer period during which attention is drawn away to the hiding of the second object. If infants represent the first-hidden object, then it is good evidence that they represent and remember both. Testing the identity change for only the first-hidden object, as opposed to the last-hidden object, provides the stronger test. Infants have to maintain the representation of the first-hidden object while attention is drawn away to an intervening object occlusion.

Káldy and Leslie found that 9-month-olds still reacted to the identity change of the first-hidden object alone. Indeed, the effect size in this new experiment was larger than with the removal of both screens. Memory for this object survived the intervening occlusion. Taken together this is the first good evidence that infants can remember the identity of two objects simultaneously.

The aim of the present study was to investigate when and how working memory for object identity develops. What is the sequence of the developmental processes necessary for infants to track *what* object went *where*? How many object identities can young infants hold simultaneously in working memory? Can young infants' memory for the identity of one object survive attention to the occlusion of an intervening object? Results of Newcombe et al. (1999) and Mareschal and Johnson (2003) suggest that object identification abilities are immature at 4–5 months of age; of Wilcox and Schweinle (2002) that they are still not robust at 5.5 months, while Káldy and Leslie (2003) have shown that memory for two simultaneous identities is well established by 9 months. Experiments 1 and 2 tested infants aged between these benchmark ages, with the same paradigm that was used by Káldy and Leslie (2003). This paradigm facilitates individuation by using two spatially separated hiding locations and enables us to investigate identification by location. Finally, Experiments 3 and 4 used a simpler one-screen paradigm and provided evidence on the role of memory decay in the *absence* of an intervening object hiding.

2. Experiment 1: shape change with two screens (both screens removed)

2.1. Method

2.1.1. Design

In order to explore 6.5-month-old infants' ability to identify objects by shape, infants were assigned randomly to one of two conditions: Shape change and No change (Control). All infants were familiarized to the same sequence of events, in which a red disk and a red triangle were placed in the middle of the stage. Each object was then moved to opposite sides of the stage (the right-hand object to the right side, and the left hand object to the left side, see Fig. 1). Crucially, the side that the two objects were presented on was alternated from trial to trial. This rules out responding by simply associating a shape feature with a side. These alternating trials are labeled Triangle/Disk (T/D) and Disk/Triangle (D/T) trials. Each familiarization trial lasted for about 21 s.

Alternating the objects' sidedness is crucial to the design because the question is whether infants can associate shape information with an object (that changes location) rather than with a fixed location. Therefore, by alternating locations between trials, a particular shape or color is associated equally with each location over the course of the experiment. Only by paying attention to the location of the object on a given trial could an infant expect a particular shape to be in a given location. This ensures that we test the binding of shape features.

Following four familiarization trials, all infants were given two test trials (see Fig. 2a). Test trials began in the same way as familiarization trials with the objects placed in the middle of the stage. Now, however, two screens were also presented, one on each side of

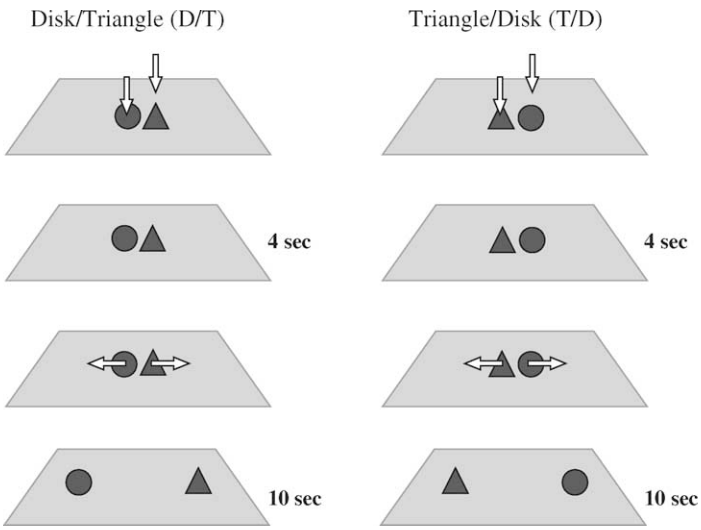


Fig. 1. Familiarization events in Experiments 1 and 2. Each infant saw four familiarization events, during which the Disk-Triangle (D/T) trial alternated with its mirror image, the Triangle-Disk (T/D) trial, and where the side of the first object (left/right) was also counterbalanced.

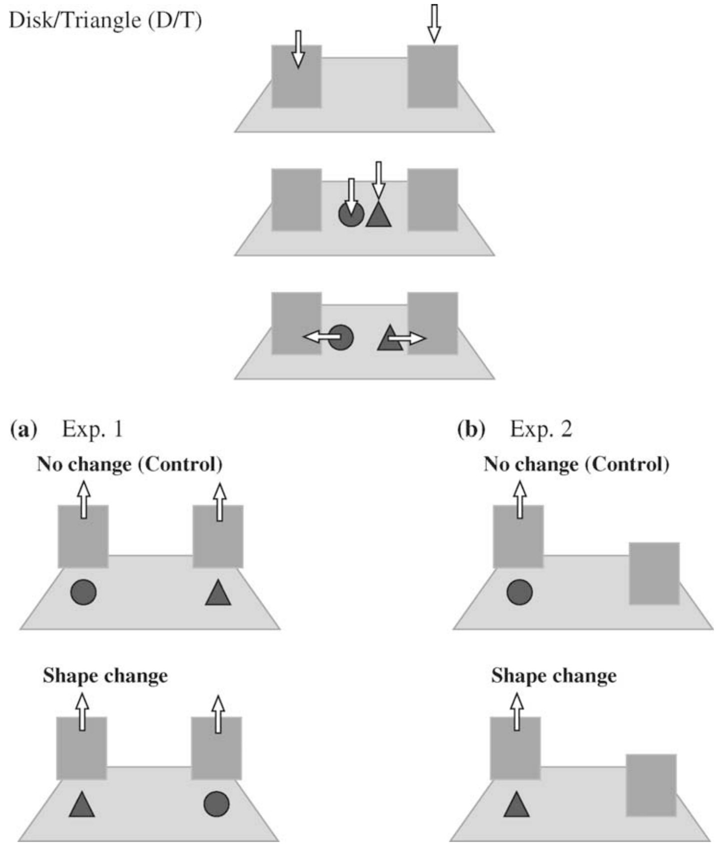


Fig. 2. Test events in (a) Experiment 1 and (b) Experiment 2. Test outcomes defined conditions for different groups of subjects in a between-subjects design. After familiarization, each infant saw two test trials, during which Disk/Triangle (D/T) alternated with Triangle/Disk (T/D) trials. Here only D/T trials are shown.

the stage. As in familiarization trials, the objects were moved to opposite sides one after the other, but this time going behind their respective screens. The screens were then removed. The initial phase of the test trial (up to the moment when the screens were removed from view) lasted for about 15 s. At this point looking time was measured and recorded.

In the No change (Control) condition, the removal of the screens revealed the same two objects in their expected locations. In the Shape change condition, the screens revealed objects swapped between locations. In this case, for instance, if the red disk was moved behind the right-hand screen and the red triangle behind the left screen, then the right screen revealed a red triangle and the left screen a red disk. Fig. 2 illustrates test trial displays by condition. Again, crucially, as in the familiarization trials, the side of presentation of the objects alternated across test trials (T/D and D/T trials).

Two factors were counterbalanced across infants. First, the order of T/D and D/T test trials was counterbalanced, so that half the infants saw a D/T, then a T/D test trial, and the other half saw a T/D, then a D/T trial. Second, the side of the object that was hidden first was counterbalanced.

2.1.2. Subjects

Twenty-four healthy, full-term infants (10 females, 14 males) participated in the study (age range: 6 months 0 days–6 months 30 days, mean age = 6 months 15 days, SD = 9.6 days), with equal number of infants in the No change (Control) and the Shape change condition. Three additional infants were tested but were excluded from the study due to experimenter error (1) or fussiness (2). Parents were recruited via local birth announcements and mailing lists from the Central New Jersey area.

2.1.3. Apparatus

Infants sat on their parent's lap facing a white, three-sided stage that was 55 cm tall, 90 cm wide and 45 cm deep at approximately 100 cm distance. The floor of the stage was covered with light-blue contact paper. The room was dimly lit, and dark blue curtains separated the testing area from the rest of the room. Two 40 W lights illuminated the stage during the trials. A black felt curtain (55 cm × 90 cm) in front of the stage was lowered (thus revealing the stage) at the beginning and raised after the end of each trial (obscuring the stage).

2.1.4. Stimuli and procedure

Red wooden triangles (base width = 10.5 cm) and disks (diameter = 10.5 cm) were used. The luminance of objects was 3.62 cd/m^2. The objects subtended approximately 3° of visual angle at the viewing distance of the infant. The objects were 0.9 cm thick and were supported by heavy wooden blocks (2 × 2 × 3 cm) affixed to their backs. Two white poster board screens (21 cm × 21 cm), which were covered with light purple construction paper, were also used. Each screen had a small (4 cm wide) supporting ledge that kept them in vertical position and also served as a hidden ledge to introduce/remove objects during the test trials.

Parents were instructed not to interact with their infants during the experiment and to close their eyes when the experimenter asked them to do so at the beginning of the test trials. The experimenter, who wore ivory-colored satin gloves and a bracelet on her right hand with four small bells on it, manipulated the objects from above. All infants were videotaped en face with a camera mounted above the stage, while another camera behind the subject recorded events on the stage. Both of these cameras were concealed, so only their lenses were visible. Video input from these cameras and audio input from a backstage microphone was sent to a mixer, a VCR, and finally to a monitor. The image on the monitor was horizontally split through a video-mixer, such that the top one-third showed a recording of the stage and the bottom two-thirds showed a head-and-shoulders view of the subject. An online observer, trained in recording infant looking times, watched this monitor with the stage view occluded and was thus blind to condition. The observer operated a two-button box connected to a computer; one button turned on the stage lights, the other button triggered timing circuits in the computer to record infant looking. The experimenter signaled when she was ready to begin a trial at which point the observer turned on the stage lights. When the experimenter removed the screens, she signaled the observer after which the observer would hold down the timing button whenever the infant appeared to look toward the stage. Whenever the infant appeared to look away from the stage, the observer released the button. The computer accumulated the looking time until the infant looked away for 2 s, at which point the computer turned off the stage lights, and recorded the accumulated looking time -2 s.

All experimental sessions were recorded on videotape and later re-scored in the same way by a second observer, who was also blind to condition. Inter-observer agreement was automatically calculated by the computer. If inter-observer agreement between the online and the offline observer was lower than 95%,[2] a third observer, also blind to condition, was used to break the tie (in approximately 10% of all cases).

2.1.4.1. Familiarization trials. Familiarization trials are illustrated in Fig. 1. Two objects, a red triangle and a red disk, were used in all familiarization trials. Experiments started with an empty stage, and then a curtain was raised to hide the stage. Stage lights were then turned on, and the curtain was lowered to reveal the lit stage. Every time an object was brought in or was moved on the stage, the experimenter shook the hand that held the object to ring the bells around her wrist, and also tapped the objects twice on the stage floor to catch the infant's attention. The experimenter placed the first object (e.g. the disk) on the stage in a position where the center of the object was 7 cm from the midline of the stage either to the left or to the right. Then she placed the second object (in this case, the triangle) with its center 7 cm away from the midline of the stage in the opposite direction. For exposition, we will call this arrangement objects in close position. The objects remained in close position for 4 s, and then in the order of their appearance, they were moved 22.5 cm in the direction of the wall that was closer to them (in example mentioned above, first the disk moved to the right, then the triangle moved to the left). This arrangement will be called far position. The objects remained in this far position for 10 s.[3] The trial ended by raising the curtain.

The sequence in which the object that appeared on the stage first was the disk was termed the Disk/ Triangle sequence (D/T) (see Fig. 1). During the familiarization trials, this sequence was alternated with its mirror image, the Triangle/Disk sequence (T/D), where the triangle was the object that appeared first. Subjects watched four successive familiarization trials. D/T and T/D sequences and the side at which the first object was placed (left/right) were counterbalanced across these trials.

2.1.4.2. Test trials. Test trials started immediately after familiarization trials and are illustrated in Fig. 2a. Test trials started by placing the screens one-by-one into far positions. In this arrangement, the edge of each screen was 5 cm away from its adjacent

[2] Let's designate Observer A's times in Trial 1 and 2 with a_1 and a_2, Observer B's times with b_1 and b_2, respectively. The formula for calculating inter-observer agreement (IOA) is: $\mathrm{IOA}=1-((a_1-b_1)+(a_2-b_2))/a_1+a_2$.

[3] Familiarization and test trials were identical to those described in Káldy and Leslie (2003), Experiment 1, No change (Control) and Shape change conditions, with one exception. Pilot studies showed that static displays engaged the younger infants' attention less. For this reason, the duration of the final, static phase of the familiarization trials was shortened from 15 to 10 s.

wall and the distance was 38 cm between them. Each screen contained an object perched on its ledge, and hidden from the infant's view. After each screen was placed onto the stage, the experimenter silently removed its surreptitiously hidden object from the ledge to a position 1 cm behind the ledge. Then the two objects that were shown in the familiarization trials, that is, the triangle and the disk, were placed one-by-one in close position, where they remained for 4 s, as in familiarization trials. After this, in order of their appearance, the triangle and the disk were moved behind the screen closer to them respectively, where, unknown to the infants, they were placed directly on the ledge. Four seconds after the second object disappeared, the screens were simultaneously raised, with the hidden objects on their ledges (and therefore removed from the stage). This revealed the pair of objects that were surreptitiously brought in with the screens. Thus, the first-hidden object was occluded for 7 s, while the last-hidden object was occluded for 4 s.

As in familiarization trials, the first object to be displayed (triangle or disk) was alternated from trial to trial. The trial where the first object was the disk is called again D/T trial, its mirror image is called the T/D trial. Infants who had seen the D/T trial in their last familiarization trial saw the T/D trial in their first test trial and vice versa.

When the screens were removed, the experimenter signaled the observer, and the recording of looking time started. The trial ended when the infant looked away for two consecutive seconds, as determined by the online observer and measured by the computer. At the end of the trial, the computer turned the lights off, and the experimenter raised the curtain. Infants watched two consecutive test trials.

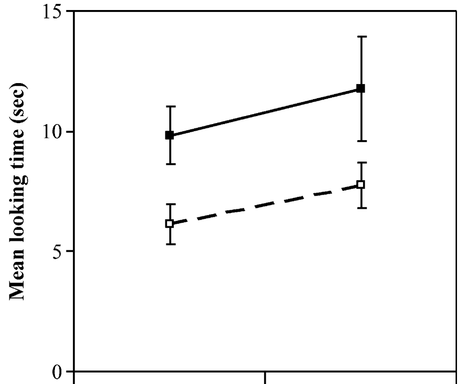
2.2. Results

One subject was excluded as an outlier (looking time: 22.80 s in Trial 1 was more than 2.5 SD from the mean of data in his condition). Data from 23 infants were used in the final analysis. Preliminary analysis showed no effect of gender, age (infants closer to 6 months vs. 7 months), first object shown (triangle/disk) or side of first object (left/right). These factors were dropped from further analysis.

Mean looking times with standard errors by condition and trial are shown in Fig. 3. Looking times were analyzed in a repeated measures 2×2 ANOVA with Trials (2) as a within-subject factor and Condition (2) as a between-subject factor.

There was no main effect of Trials ($F_{1,21}<1$), but the main effect of Condition was significant ($F_{1,21}=6.62$, $P=0.018$). Effect size was estimated using η^2: shape change accounted for 24% of the overall variance. There was no significant interaction between the two factors ($F_{1,21}<1$).

Planned comparisons with Student's t compared looking times in the two test trials for the experimental groups with the control group. Looking times in the Shape change condition were significantly different ($t_{21}=2.47$, $P=0.022$, two-tailed) from controls in Trial 1, but not in Trial 2 ($t_{21}=1.69$, $P=0.11$, two-tailed). Non-parametric tests (Mann–Whitney) showed similar results: for Trial 1, $z=2.15$, $P=0.032$; for Trial 2, $z=1.17$, $P=0.26$ (two-tailed tests).



	Trial 1	Trial 2
Shape change	9.84	11.76
No change	6.13	7.74

Fig. 3. Mean looking times in Experiment 1 by condition and trial (in seconds). Error bars represent ± 1 SE of the mean.

2.3. Discussion

Experiment 1 showed that 6.5-month-old infants are able to use featural information (shape) to identify objects by location in the same paradigm that 9-month-olds do. Infants of this age are able to bind shape information to an object representation and subsequently use that information to identify the object after it has been revealed.

Did infants in Experiment 1 remember the shape of both of the objects, or only one of the objects? Their response might have been based on information just from the last-hidden object, given that information about the last-hidden object need only remain in memory for a relatively short period before the screen is removed, as compared to the first-hidden object. Attending only to the last-hidden object would allow detection of change with a lesser memory load; while recognizing the change in the first-hidden object would require a higher memory load. We raised the same question in a previous study with 9-month-old infants (Káldy & Leslie, 2003), and found that these infants did, in fact, remember the object with the higher memory load. In experiment 2, we address this issue again but in regard to younger infants.

3. Experiment 2: shape change with two screens (only first screen removed)

In all multiple object experiments, the question of whether infants attend to all of the objects or just a subset of them arises, but is seldom addressed. In order to test whether infants merely sample one of the objects or remember both objects in our two-screen paradigm, a second experiment was conducted. In this new version only one of the screens was removed, namely, the one that hid the *first*-hidden object. Removing this screen provides the ‘harder’ test. For example, if the triangle had moved behind the left screen and then the disk had moved behind the right screen, only the left screen would be removed. In the No change (Control) condition, the screen would reveal a triangle, while in the Shape change condition it would reveal a disk. If both screens are removed together, as in experiment1, infants might look longer because they detected only that the ‘easy’ last hidden object had changed unexpectedly, not because they detected that both hidden objects had changed. The sub-sampling hypothesis was tested by revealing only the first-hidden object, as opposed to the last-hidden object, because this provides a stronger test.

3.1. Method

3.1.1. Design

Experiment 1 was repeated, but this time only one of the screens was removed (see Fig. 2b for test events). The removed screen was always the one for the *first*-hidden object. Therefore, infants had to remember this object while the second object was moved and hidden behind the other screen.

Crucially, in this experiment as in Experiment 1, D/T and T/D trials alternated with each other. That is, if the first familiarization trial began with a disk on the right, then the next trial would begin with a triangle on the right. This trial-by-trial alternation of shape by side continued throughout the experiment, including throughout the test trials. Shape by side was counterbalanced, so that half the infants began with the disk on the right and half began with the triangle on the right. Alternating sidedness of shape prevents infants from simply associating a given shape with a particular side of the stage because across trials each shape will be associated equally often with each side. Instead, infants must attend to the particular side of a given shape *on each trial*, if they are to notice an unexpected outcome.

3.1.2. Subjects

Thirty-two healthy full-term infants (18 females, 14 males) participated in the study (age range: 6 months 0 days–6 months 30 days, mean age = 6 months 14 days, SD = 10.2 days), with 17 infants in the No change (Control) and 15 in the Shape change condition. Six additional infants were excluded due to experimental error (3), equipment failure (1) or fussiness (2). Parents were recruited in the same manner as in Experiment 1.

3.1.3. Apparatus, stimuli and procedure

The apparatus and stimuli were the same as in Experiment 1. Familiarization and test procedure was the same as in Experiment 1, except that in the outcome phase only one of the screens was removed (for test trials, see Fig. 2b). Only the screen occluding the *first* object to be hidden was removed. The other screen that was hiding the last object remained in far position on the stage. The time elapsed between hiding and revealing the first object was approximately 7 s.

Data measuring and recording methods were the same as in Experiment 1. Inter-observer agreement was 95% or higher in all cases.

3.2. Results

One subject was excluded as an outlier (looking time: 35.7 s in Trial 2, more than 2.5 SD from the mean data of his condition). Data from 31 infants were used in the final analysis.

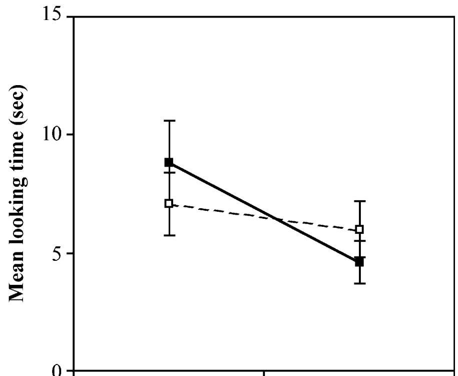
Preliminary analysis showed no effect of gender, age, first object shown (triangle/disk) and side of first object (left/right), and these factors were dropped from further analysis.

Mean looking times with standard errors by conditions and by test trials are shown in Fig. 4. Looking times were analyzed in a repeated measures 2×2 ANOVA with Trials (2) as a within-subject factor and Condition (2) as a between-subject factor. The main effect of Trials was significant ($F_{1,29}=4.91$, $P=0.035$), reflecting declining looking times across trials, while the main effect of Condition was not significant ($F_{1,29}<1$, P n. s.). The two factors did not interact significantly ($F_{1,29}=2.97$, $P=0.095$), but looking times in the Shape change condition group tended to decline more across trials.

Effect size was estimated using η^2: shape change accounted for approximately 0% of the variance. Planned comparisons with Student's t compared looking times for the experimental group with the control group for each test trial. Looking times in the Shape change condition were not significantly different from controls (Trial 1, $t_{29}=0.79$, $P=0.44$, Trial 2, $t_{29}=0.92$, $P=0.36$, two-tailed tests). Non-parametric tests showed similar results: for Trial 1, $z=0.69$, $P=0.48$; for Trial 2, $z=0.83$, $P=0.42$ (two-tailed tests).

3.3. Discussion

Experiment 2 demonstrated that 6.5-month-old infants did not remember the shape of the *first* hidden object in the two-screen paradigm. The results of Experiment 1 and 2 together suggest that 6.5-month-old infants only remember the *last* hidden object in our



	Trial 1	Trial 2
Shape change	8.78	4.59
No change	7.06	5.99

Fig. 4. Mean looking times in Experiment 2 by condition and trial (in seconds). Error bars represent ±1 SE of the mean.

object-location task, and this was the reason for the longer looking times in the unexpected condition of Experiment 1. This result of Experiment 2 is congruent with Wilcox and Schweinle's (2002) results with a similar paradigm, but it is in sharp contrast with the earlier reported positive results with older, 9-month-old infants using the same paradigm (see Káldy & Leslie, 2003), an issue that we will return to in the general discussion.

4. Experiment 3: shape change with one screen

4.1. Method

4.1.1. Design

Results of Experiment 1 suggested that identifying an object based on shape is within 6-month-olds' capabilities but is limited to a single object at a time. To directly address this question, Experiment 3 used a simplified paradigm, where only one screen and one object per trial was shown.

Familiarization trials are shown in Fig. 5.

Four familiarization and two test trials were run. Although we used a single object and a single screen, we still used a trial-by-trial alternation method, so that infants had to track the object on a trial-by-trial basis in order to detect an unexpected shape change. Disk and triangle trials alternated from trial to trial during familiarization and test trials. If the object in last the familiarization trial was a disk, then the first test trial presented a triangle and vice versa. Test trials are shown in Fig. 6.

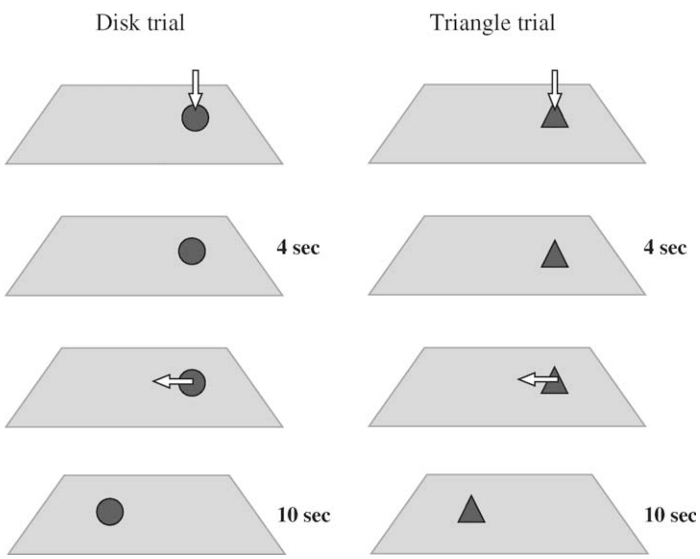


Fig. 5. Familiarization events in Experiment 3. Each infant saw four familiarization events, during which disk trials alternated with triangle trials. The shape of the first object in the sequence was counterbalanced.

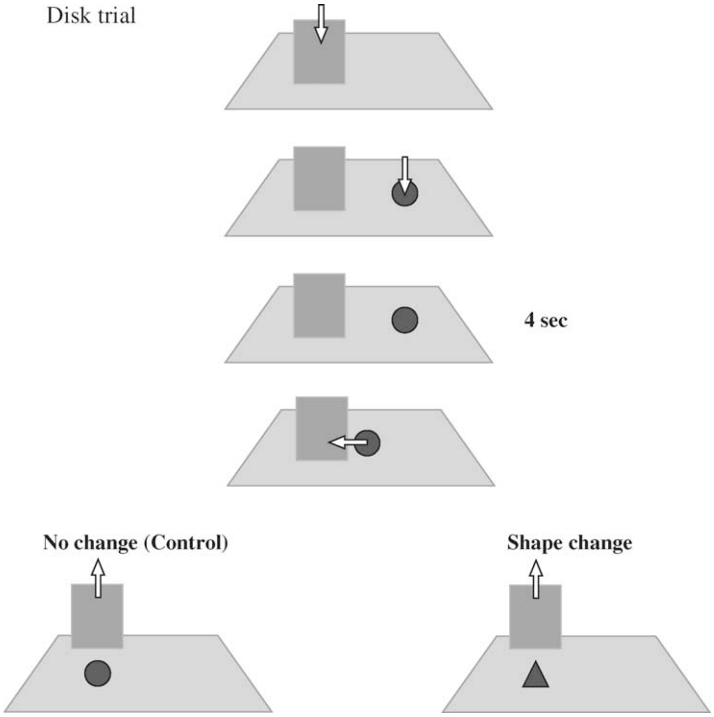


Fig. 6. Test events in Experiment 3 by condition. After familiarization, each infant saw two test trials, during which disk trials alternated with triangle trials. Here only disk trial is shown.

4.1.2. Subjects

Twenty-five healthy full-term infants (11 females, 14 males) participated in the study (age range: 6 months 0 days-6 month 30 days, mean age = 6 month 12 days, SD = 8.13 days), 12 in the No change (Control) and 13 in the Shape change condition. Four additional infants were tested but excluded due to experimental error (1) or fussiness (3). Parents were recruited the same way as in Experiment 1.

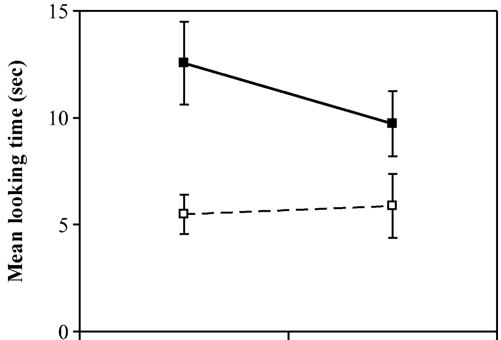
4.1.3. Apparatus, stimuli and procedure

The apparatus and stimuli were the same as in Experiment 1, except only one screen was used. The time elapsed between hiding and revealing the object was approximately 4 s—corresponding to the hiding time of the second object in Experiments 1 and 2.

Data measuring and recording methods were the same as in Experiment 1. Inter-observer agreement was 95% or higher in all cases.

4.2. Results

Preliminary analysis showed no effect of gender, age, first object shown (triangle/disk) and these factors were dropped from further analysis.



	Trial 1	Trial 2
Shape change	12.55	9.72
No change	5.48	5.87

Fig. 7. Mean looking times in Experiment 3 by condition and trial (in seconds). Error bars represent ± 1 SE of the mean.

Mean looking times with standard errors by conditions and by test trials are shown in Fig. 7. Looking times were analyzed in a repeated measures 2×2 ANOVA with Trials (2) as a within-subject factor and Condition (2) as a between-subject factor. There was no effect of Trials ($F_{1,23}<1$). The main effect of Condition was highly significant ($F_{1,23}=11.53$, $P=0.002$). There was no significant interaction between the two factors ($F_{1,23}=1.20$, $P=0.28$).

Effect size was estimated using η^2: shape change accounted for 33.4% of the variance. Planned comparisons with Student's *t* compared looking times in the two test trials for the experimental groups with the control group. Looking times in the Shape change condition were significantly different ($t_{23}=3.20$, $P=0.004$, two-tailed) from controls in Trial 1, and showed a tendency in Trial 2 ($t_{23}=1.79$, $P=0.086$, two-tailed). Non-parametric tests showed similar results: for Trial 1, $z=2.83$, $P=0.004$; for Trial 2, $z=1.96$, $P=0.052$ (two-tailed tests).

4.3. Discussion

The simplified paradigm of Experiment 3 directly tested object identification by shape using one object and one screen per trial. The results showed that infants tracked and remembered the shape of the object from trial to trial and looked longer when the shape of the object had been surreptitiously changed.

Turning to the difference between the results of Káldy and Leslie (2003) who found that 9-month-olds succeeded with a first-hidden object shape change, whereas our present results with 6-month-olds show success only with the last-hidden object, we can propose the following hypothesis. Younger infants have succeeded only in those versions of the task where the amount of time while the objects were occluded was relatively short (4 s), while older infants succeeded with both shorter (4 s) and longer occlusion times (7 s). We hypothesize that the failure of young infants in Experiment 2 was not a result of the added distraction of another object or the fact that their attention to the first hiding location was interrupted, but was the result of the fast temporal decay of the memory trace. However, several different memory studies have found positive results with much longer delay times in infants aged 5–8 months (Baillargeon, DeVos, & Graber, 1989; Baillargeon & Graber, 1988; Luo, Baillargeon, Brueckner, & Munakata, 2003; Rose, Feldman, & Jankowski, 2001). In order to test this hypothesis, a fourth experiment that replicated Experiment 3 with a longer, 7 second delay was conducted.

5. Experiment 4: shape change with one screen and longer delay

5.1. Method

5.1.1. Design

The design of the experiment was identical to that of Experiment 3, except in the test trials, objects were hidden for a longer period of time (7 s)—matching the delay time of the first-hidden object in Experiments 1 and 2.

5.1.2. Subjects

Twenty-four healthy full-term infants (12 females, 12 males) participated in the study (age range: 6 months 0 days-6 month 30 days, mean age = 6 month 11 days, SD = 9.28 days), equal number of them in the No change (Control) and the Shape change condition. 3 additional infants were tested but excluded due to experimental error (1) or fussiness (2). Parents were recruited the same way as in Experiment 1.

5.1.3. Apparatus, stimuli and procedure

The apparatus, stimuli and procedure of this experiment were identical to that of Experiment 3, except in the test trials, objects were hidden for a longer period of time (7 s).

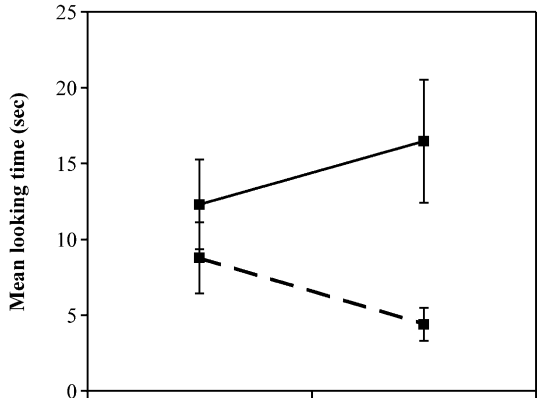
5.2. Results

Preliminary analysis showed no effect of gender, age, first object shown (triangle/disk) and these factors were dropped from further analysis.

Mean looking times with standard errors by conditions and by test trials are shown in Fig. 8. Looking times were analyzed in a repeated measures 2×2 ANOVA with Trials (2) as a within-subject factor and Condition (2) as a between-subject factor.

There was a significant effect of Condition: $F_{1,22} = 5.654$, $P < 0.02$, but not of Trials ($F_{1,22} < 1$), and no significant interaction between the two factors ($F_{1,22} = 3.470$, $P < 0.07$), though looking times in the unexpected condition trended higher while controls declined.

Effect size was estimated using η^2: shape change accounted for 20.4% of the variance. Planned comparisons with Student's *t*-test compared looking times in the two test trials for the experimental group with the control group. The observed looking time difference between the two groups was not significant in Trial 1: $t_{22} = 0.931$, $P < 0.36$, but was highly significant in Trial 2: $t_{22} = 2.867$, $P < 0.014$ (two-tailed tests). Non-parametric tests



	Trial 1	Trial 2
Unexpected	12.3	16.47
Expected	8.78	4.4

Fig. 8. Mean looking times in Experiment 4 by condition and trial (in seconds). Error bars represent ± 1 SE of the mean.

(Mann–Whitney) showed similar results. Trial 1: $z = 1.097$, $P < 0.29$ Trial 2: $z = 2.628$, $P < 0.007$ (two-tailed tests).

5.3. Discussion

Results of Experiment 4 showed that infants at 6.5 months of age were able to identify objects by shape even with longer delays (7 s). The length of this delay was identical to the amount of time the first object was occluded in Experiment 2, where we found negative results. The only difference between the two experiments was that during this delay infants saw another object being hidden in Experiment 2, but not in Experiment 4. Therefore, fast memory decay by itself will not explain younger infants' failure to identify the first-hidden object. Instead, it seems that when a subsequent and intervening object-hiding draws attention away, the identity of the previously seen object drops out of infants' memory. Below (Section 6.2) we discuss possible neural substrates for this effect.

6. General discussion

The present study explored object identification abilities of 6.5-month-old infants. There were two major findings: first, 6.5-month-olds were able to identify objects based on shape in a simple task where the objects were occluded for a few seconds. Secondly, this ability seemed to be fragile and appeared to break down when infants' attention was distracted during the memory maintenance period with an intervening item. When there was no intervening item (Experiments 3 and 4), six-month-olds succeeded in identifying by shape, even when the retention period was as long as it had been when they failed with an intervening item. This suggests that it is the intervening item, rather than the delay entailed by itself, that produces difficulty for the younger infant.

Whereas delay by itself cannot account for our findings, there may yet be an effect of delay in combination with the intervening item. If the second object had been occluded for 5 min rather than the 4 s as in experiment 2, 6-month-old infants might fail (however, see Luo et al., 2003). Nevertheless, we must assume that processing an intervening item is critical to their failure. What remains to be decided by future research is whether, to produce this effect, the intervening object simply has to become the focus of attention or whether the intervening item actually has to be hidden. It may be that the attempt to store identity information about the last-hidden object causes the identity information for the old object to be dropped.

It is also important to notice that infants could not simply associate objects with particular locations in our paradigm, since the sidedness of the objects was alternated from trial to trial. This was an essential feature of our design. Suppose the same shaped object had been presented on the same side throughout all trials. In this case, infants could simply have habituated by associating, for example, 'roundness' with the left of the stage and 'triangularity' with the right. On test trials, infants would then have simply reacted to a novel pairing of shape and location without telling us anything useful about object representation. Instead, by alternating shape by side from trial to trial throughout both familiarization and test, each shape is equally associated with each side. Infants were forced to pay attention on each trial to which object went behind which screen. Only if they do this could it be surprising that on a particular trial a particular screen reveals a particular shape. Presumably, a task that requires infants to update their representation of the scene from trial to trial is more demanding on visual working memory (Leslie & Káldy, 2001), than a task in which a stable representation can be constructed across trials. Nevertheless, infants succeeded in our task in Experiments 1, 3 and 4.

6.1. Neurophysiological development of object identification

These results are particularly interesting in relation to our earlier findings reported in Káldy and Leslie (2003). A developmental pattern of successes and failures in object identification is summarized in Table 1.

Summing up the results of the present study and of Káldy and Leslie (2003), we can say that between 6.5 and 9 months of age infants become capable of (1) identifying two objects by feature *and* location, that is, integrating *what* and *where* information in two separate

Table 1
Findings of the present study contrasted with results of Káldy and Leslie (2003)

		6.5-month-olds	9-month-olds	
		Shape	Shape	Color
Two screens	Both removed	✓	✓	×
	Only first one	×	✓	×
One screen		✓	✓	

For the study involving 9-month-olds and one screen, see Káldy and Leslie (2002). Checkmarks indicate success; ×, symbols indicates failure.

representations, and (2) remembering the identity of an object, even after their attention is redirected to a second object hiding during the memory delay period. Since there were no significant age trends within either of the two samples, the predictions regarding the time of the shift can be limited to the period between 7 months and 8.5 months. Let's examine the neurophysiological implications of these two results in turn.

6.2. Integrating 'what' and 'where' information

Higher level processing of visual information is more or less segregated into two separate cortical streams in the brain: one is more concerned with object recognition, the other one with space and visually guided action. We interpreted our results with 9-month-old infants (Káldy & Leslie, 2003) as evidence for integration of information from these two streams, since these infants were able to use features to identify objects, binding shape information to object representations at specific locations. Shape information is represented in both the ventral and the dorsal streams (Kraut, Hart, Soher, & Gordon, 1997; Murata, Gallese, Luppino, Kaseda, & Sakata, 2000). However, we do not think that our 9-month-old infant subjects were relying on dorsal shape representations, since in adults these representations are active only briefly, for less than 5 s (Hu & Goodale, 2000) and only *after* an action is cued and while the target remains visible (Westwood & Goodale, 2003). None of these conditions obtained in our experiments with infants: target objects were invisible for more than 5 s and did not cue action. We therefore believe it is unlikely that dorsal shape information was available to our infants and must therefore have been represented ventrally. However, information from the dorsal stream was needed in order to localize the objects in our tasks. Putting this together suggests that the integration of ventral and dorsal streams—the 'what' and 'where'—is in place by 9 months for two objects and by 6.5 months for a single object. We discuss the specific involvement of the ventral stream in Section 6.2.1.

6.2.1. A memory span of one?

Regarding the failure at 6.5 months of age to remember the first one out of two serially hidden objects, we have formulated a hypothesis that allows us to make connections with some recent neuroscientific findings. This hypothesis is that in the gradual process of object working memory development, 6.5-month-old infants are at a stage when they can detect an identity violation by features in a memory task, but not if they see an intervening object in the retention period. (For a more detailed discussion of this hypothesis, see Káldy & Sigala, 2004)

In monkeys, visual recognition memory is most commonly measured by the 'delayed matching to sample' (DMS) task. Typically in these studies, a sample object is presented at the start of the trial, followed by a delay and then one or more test objects shown sequentially. The monkey is rewarded for indicating which test object matches the sample. According to Suzuki (Suzuki, 1999; Suzuki, Miller, & Desimone, 1997), a particular part of the medial temporal cortex called the entorhinal cortex demonstrates memory-related responses while the monkey is working on the DMS task. In the standard version of the DMS task, a given non-match test object is presented only once within a given trial. For example, a particular stimulus sequence in a trial might be ABCA ('A' being the sample), in which the B and the C appear only once in the sequence. In a new variation first used by Miller and Desimone (1994), one of the non-matching test stimuli is repeated within the sequence (for example, the sequence might be ABBA). Suzuki et al. (1997) have shown that memory-related responses in the entorhinal cortex are only characteristic of the to-be-remembered object (in this example, the A object). In other words, these cells do not react to the simple repetition of item B. In addition to this, these responses persist even with several intervening items between the sample and the match.

The ABBA task and the two-object-two-screen task that we used in Experiment 2 have a number of similarities. The subject only 'passes' the test if he or she is able to identify an item as being the same or different than a previous item—even if they have seen some other objects in the meantime. One difference between the tasks is that monkeys are trained to actively remember features of objects, whereas our infants respond spontaneously. The significance of this difference deserves further study. Nevertheless, evidence from the neuroscientific literature clearly indicates that the entorhinal cortex, as well as other medial temporal areas such as the parahippocampal cortex, plays a crucial part in object-location memory, and we hypothesize that a significant step in the maturation of these areas makes the behavioral shift between 7 and 8.5 months possible. Younger, 6.5-month-old infants can only hold on to the last object that they have seen occluded, but by 9 months, infants become capable of holding an object in working memory while their attention is distracted by the movement and hiding of an intervening object.

6.3. Summary of recent results on object identification

Finally, we summarize results from seven recent studies of object identification in infancy. Table 2 shows the observed pattern of successes and failures in eight different age groups ranging from 4 to 12 months.

Table 2
Summary of results on object identification capabilities in infancy

Object identification	**M&J**	**N *et al.***	**S *et al.***	**W&S**	**K&L2**	**W&S**	**K&L1**	**T *et al.***	
age (months)	4	5	5	5.5	6.5	7.5	9	12	
BY FEATURE	√	√	**X**	**X**	√	√	√	**X**	√
BY LOCATION	√	√		√					
BINDING FEATURE AND LOCATION	**X**	**X**			**X**		√		

Featural difference used in studies: shape (indicated by light grey shading), color (indicated by dark grey), complex featural difference: shape, color and texture (indicated by no shading). List of studies cited: M&J: Mareschal and Johnson (2003); N et al.: Newcombe et al. (1999); S et al.: Simon et al. (1995); W&S: Wilcox and Schweinle (2002); K&L1: Káldy and Leslie (2003); K&L2: Káldy and Leslie (present publication); T et al.: Tremoulet et al. (2000). Checkmarks indicate success; ×symbols indicates failure.

These studies have used different stimuli (real objects vs. computer-animated images), different methods (habituation vs. familiarization, within- vs. between- subjects designs, event-mapping vs. event-monitoring) and tested different perceptual features (shape, color or complex differences between toys: see Table 1). A few trends seem to be clear already. Identification by feature starts developing relatively early, with the exact age depending on the particular feature dimension in question. There is also some evidence pointing to early capabilities of object identification by location, but more studies are needed. Binding features to two distinct object representations and keeping track of their respective locations is a capability that so far has only been found in 9-month-old infants.

6.4. In conclusion

The study of the questions first raised by Gerald Gratch in the 1970s has gained new impetus in the past few years. These studies point to an important developmental trend during the first year of life: infants' capacity to remember features of objects and identify them based on these features develops gradually. Tracking the locations of the objects so identified is an even more complex task. Our present recent results show that 6.5-month-old infants are able to track only one object and identify it by shape. If a second object is introduced, these infants loose track of the identity of the first one, and only remember the last one reliably. Delay times in these serial tasks are important, but by itself do not explain the apparent lack of memory. Instead, the role of the intervening item must be considered. By 9-months, however, infants can maintain two separate object representations at the same time and identify objects based on location as well as on feature: they know *what* object of two went *where*. The study of the unfolding of the remarkable ability to keep track of objects in the world continues.

Acknowledgements

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