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PAPER

Identification of objects in 9-month-old infants: integrating 'what' and 'where' information

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Abstract

Following Leslie, Xu, Tremoulet and Scholl (1998), we distinguish between individuation (the establishment of an object representation) and identification (the use of information stored in the object representation to decide which previously individuated object is being encountered). Although there has been much work on how infants individuate objects, there is relatively little on the question of when and how property information is used to identify objects. Experiment 1 shows that 9-month-old infants use shape, but apparently not color, information in identifying objects that are each moved behind spatially separated screens. Infants could not simply have associated a shape with a location or a screen without regard to objecthood, because on alternate trials the objects switched locations/screens. Infants therefore had to bind shape information to the object representation while tracking the objects' changing location. In Experiment 2, we tested if infants represented both objects rather than 'sampled' only one of them. Using the same alternation procedure, infants again succeeded in using shape (but not color) information when only one of the screens was removed – the screen that occluded the first-hidden object (requiring the longer time in memory). Finally, we relate our behavioral findings both to a cognitive model and to recent neuroscientific studies, concluding that ventral 'what' and dorsal 'where' pathways may be functionally integrated by 9 months.

Introduction

Studies of infants in the past two decades have established that they are sensitive to a range of object properties, including permanence, volume, solidity, spatiotemporal continuity and causal power (e.g. Baillargeon, 1986, 1987; Baillargeon, Spelke & Wasserman, 1985; Leslie & Keeble, 1987; Spelke, 1988, 1994; Spelke, Breinlinger, Macomber & Jacobson, 1992). However, infants do not always make adult-like judgments about the individuation of objects based upon their features (Xu & Carey, 1996; Simon, Hespos & Rochat, 1995; Wilcox & Baillargeon, 1998).

Leslie, Xu, Tremoulet and Scholl (1998), drawing upon the literature on adult attention, introduced to the infancy literature a distinction between *individuation* and *identification*. Individuation refers to the detection of a novel target object and the resulting establishment of an object representation (OR). Detection of further objects results in the establishment of additional ORs. Individuation thus forms the basis for answering the question, 'how many?'

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 to which object the OR refers. Identification thus answers the question, 'which one?'

In an influential study (Xu & Carey, 1996), 10- and 12-month-olds were familiarized with a display in which a toy duck is removed from and placed back behind an occluding screen, followed by a toy truck which is taken out from and replaced behind the same screen (the 'property' condition). When the screen was removed, 10-month-olds showed baseline looking when only one of the objects was revealed, suggesting that they did not expect two objects behind the screen. Only when these infants had an opportunity to see both objects simultaneously (the 'spatiotemporal' condition), did they show looking times different from baseline to a single object display. Xu and Carey argued that their 10-month-old infants individuated the objects on the basis of their occupying distinct locations at the same time but not on

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the basis of their featural differences seen across time. Recently, Wilcox and Baillargeon (1998) and Wilcox (1999) have found that, under certain simplified presentation conditions, younger infants (4–9 months) can use featural information to individuate objects. However, none of these studies addressed the question of infants' ability to use featural information to *identify* objects.

For concreteness, the distinction between individuation and identification can be illustrated with respect to Xu and Carey's (1996) design. How would their infants have reacted if there had been a condition in which the screen was removed to reveal either two ducks or two trucks? From the point of view of individuation, such a display should have been expected because the number of objects revealed is two. However, from an adult point of view, the identity of one of the objects is unexpected. In order to detect the unexpected identity, information about the properties of the objects – for example, duck-shape and truck-shape – would have to be associated with the ORs established for the respective objects. That is, it would not be enough merely to have established an OR for each of the objects. As long as two objects were revealed, without any identifying information available, it would not matter if they were duck + duck or truck + truck, because either pair would act as referents for the two ORs, just as well as duck + truck would.

We cannot tell from Xu and Carey's (1996) data whether their infants had specific identity expectations. Similarly, in Wilcox's two previously published reports (Wilcox, 1999; Wilcox and Baillargeon, 1998), only the question of individuation was addressed.

In our laboratory we have been studying the development of infants' abilities to identify objects by way of property information (e.g. by shape). We familiarize infants with a triangle and a disk, displaying each, one at a time, drawn from and returned behind a screen. Following familiarization, the screen is removed to reveal (unexpected condition) either two disks or two triangles. At 6 months of age, infants do not look longer at the two-disk or the two-triangle display; nor do they look longer at this outcome following familiarization with disk and triangle displayed simultaneously, that is, given spatiotemporal information for individuation (Krauss & Mathur, 1999). Under similar testing conditions at 9 months of age, infants also failed to identify objects by shape (Tremoulet, Lee & Leslie, 1998). Indeed, it is not until 12 months of age that we have obtained our first evidence for identification of objects by shape with sequential presentation (Tremoulet, Leslie & Hall, 2000). In Tremoulet *et al.*, 12-month-old infants looked significantly longer at the two identical objects outcome than in a control condition where the screen revealed the expected disk and triangle. This implies that these infants expected not simply and indifferently two things, but expected exactly one of the things to be a disk and the other to be a triangle. This in turn shows that, under these testing conditions, 12-month-olds will bind shape information to stored ORs.

In the same series of experiments, Tremoulet *et al.* (2000) studied identification by color in 12-month-olds. In this experiment, infants were familiarized with a red disk followed by a green disk, each sequentially drawn from and returned behind a screen. The two disks were never displayed together. Following familiarization, infants were tested by removing the screen to reveal either two red or two green disks. Across three separate experiments, including one in which the objects were presented together during familiarization, infants failed to look longer than controls who saw the expected outcome, suggesting that the infants did not use color information to identify the objects.

Interestingly, infants in Tremoulet *et al.* did not simply ignore color altogether. In one experiment, 12-month-old infants did use color information to *individuate* the objects. Infants familiarized with a single red disk looked longer when the screen revealed two red disks than infants familiarized sequentially to one red and, say, one green disk. The color difference led the infants to individuate the objects across presentations but without inducing the expectation that the objects should have specific colors or even differ in color when the screen was removed. Tremoulet *et al.* concluded that, at 12 months, infants will establish distinct ORs in response to color information but will not automatically bind that color information to the ORs so established. Many accounts make the commonsense assumption that success at individuation by feature must necessarily entail identification by that feature. Tremoulet *et al.*'s data suggest that that assumption is false.

It is relatively uncontroversial that by 12 months infants can use features to individuate objects (Xu & Carey, 2000; Needham & Baillargeon, 2000; Tremoulet *et al.*, 2000). What is controversial is whether infants younger than about 10 months (the younger age group in the Xu & Carey (1996) experiments) can do the same. Xu and Carey (1996, 2000) claim they cannot, while Needham and Baillargeon (2000) claim they can (see also Wilcox, 1999; Wilcox & Baillargeon, 1998), at least with simplified tasks. Many tasks require infants to make inferences about the relation between a display with an occluder and a later display in which the occluder is removed. Baillargeon and colleagues call such tasks 'event mapping' tasks and argue that these tasks make demands that only older infants can meet. When displays are simplified in such a way that the occluder is not removed – an 'event monitoring' task

– infants show evidence of individuating by property much earlier, as young as 4.5 months, than with 'event mapping' tasks (Wilcox, 1999). The evidence suggests that individuation by feature or property is a somewhat fragile ability in infants younger than about 10 months.

As we noted earlier, identification has been much less studied than individuation and we know little about identification by feature in younger infants. Besides the Tremoulet *et al.* study described above, Simon, Hespos and Rochat (1995) have studied identification and found that despite individuating by location, 5-month-olds do not identify objects by feature. The featural differences between the two objects used in their study (an Ernie and an Elmo doll), however, were complex and difficult to quantify. In a recent study, Wilcox and Schweinle (2002) investigated individuation and identification in 5.5- and 7.5-month-old infants. They found evidence for identification abilities at 7.5 months, but again, the featural difference between the two objects in the study was complex (shape, color and pattern differences).

Given the fragility of individuation by feature in infants younger than 10 months, one might expect identification by feature to be even more difficult. However, where individuation has been driven by location information, infants might be better able to bind feature information to the resulting ORs (Leslie *et al.*, 1998). Because our goal was to look for evidence of object identification, we facilitated individuation by using two spatially separated screens. This way we could address a further question that goes beyond individuation and identification, namely the issue of location itself. It is possible that the infant knows how many objects he or she did see and even what color or shape they had, but not know exactly where they were. (With one screen all objects are in the same 'mental' location, namely, behind the screen.) The 'what' and 'where' distinction is important for neuroscientific theories of visual organization. Do infants know *what* went *where* (identification-by-location)? Study of object tracking in infancy can make an important contribution to the larger framework of developmental cognitive neuroscience.

Experiment 1

Method

Design

In order to explore 9-month-old infants' ability to identify objects on the basis of shape and color, infants were assigned randomly to one of four conditions: Color change, Shape change, Shape and Color change, No change (Control). All infants were familiarized to the same sequence of events, in which a red disk and a blue triangle were placed in the middle of the stage. Then each object was 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 Figure 1). Crucially, the side that the two objects were presented on was alternated from trial to trial. We shall call these alternating trials Triangle/Disk (T/D) and Disk/Triangle (D/T) trials.

Alternating the objects' sidedness is crucial to our design because we want to test whether infants can associate shape and color 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 or color to be in a given location.

Following four familiarization trials, all infants were given three test trials. 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 the stage. As in familiarization trials, the objects were moved to opposite sides, but this time going behind their respective screens (see Figure 2). The screens were then removed. 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 Color change condition, the screens revealed objects with the expected shape, but with colors swapped across locations. Thus, if the red disk was moved behind the right-hand screen and the blue triangle behind the left screen, then the right screen revealed a blue disk and the left screen a red triangle. In the Shape change condition, the screens revealed objects with the expected color but with shape swapped across locations. Thus, if the red disk was moved behind the right-hand screen and the blue triangle behind the left screen, then the right screen revealed a red triangle and the left screen a blue disk. In the Shape and Color change condition, the screens revealed the objects swapped across locations. Thus, if the red disk was moved behind the right-hand screen and the blue triangle behind the left screen, then the right screen revealed the blue triangle and the left screen the red disk. Figure 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 counter-

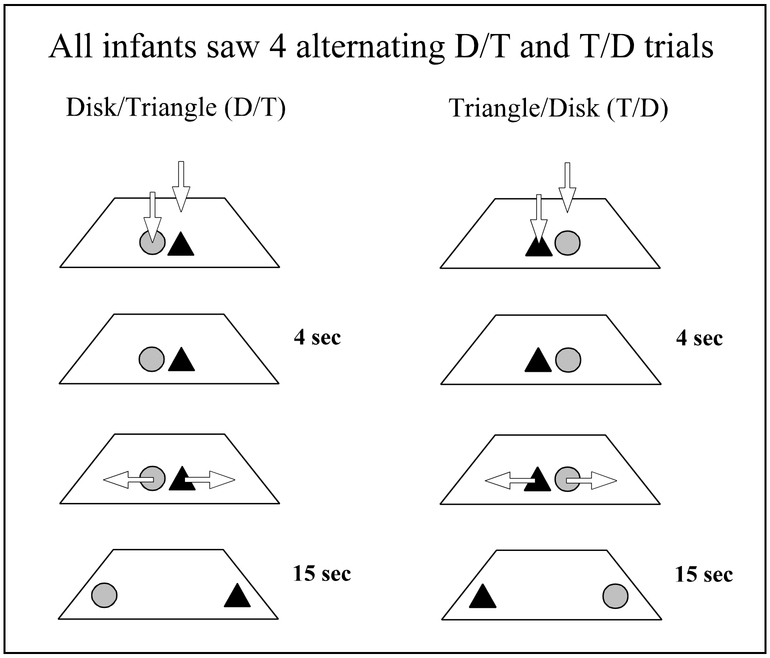


Figure 1 *Familiarization events. Each infant saw 4 familiarization events, during which the Disk-Triangle (D/T) trial alternated with its mirror image, the Triangle-Disk (T/D) trial, and where the side of the first object (left/right) was also counterbalanced. Color differences are represented here as differences in luminance.*

balanced, so that half the infants began with a T/D test and thus received T/D, D/T and T/D trials, while the other half began with D/T and received D/T, T/D and D/T. Second, the side of the object that was hidden first was counterbalanced.

Subjects

Sixty-four healthy, full-term infants (33 females, 31 males) participated in the study (age range: 8 months 15 days–9 months 15 days, mean age = 8 months 26 days, SD = 8.9 days). Twenty subjects were in the No change (Control) and the Shape and Color change conditions, 12 subjects were in the Color change and the Shape change conditions. Eight additional infants were excluded from the study due to observer error (2), fussiness (5) or inter-observer disagreement (1). Parents were recruited via local birth announcements and mailing lists from the Central New Jersey area.

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 at the beginning and raised after the end of each trial.

Stimuli and procedure

Blue and red wooden triangles (base width = 10.5 cm) and blue and red disks (diameter = 10.5 cm) were used. The average luminance of the blue and red objects was 2.94 and 3.62 cd/m^2, respectively. 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 was used to hide the objects during the test trials.

Parents were instructed not to interact with their infants during the experiment and also to close their eyes when the experimenter asked them to do so at the beginning of the test trials. The objects were manipulated from above by the experimenter, who wore ivory-colored satin gloves and a bracelet on her right hand with four small bells on it. All infants were videotaped

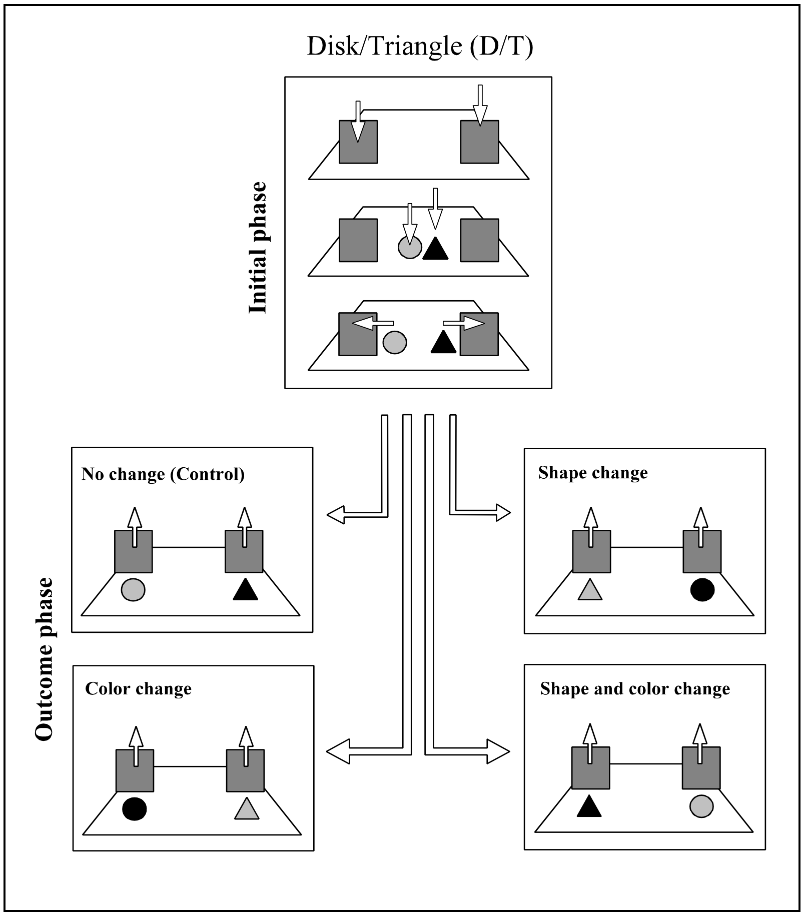


Figure 2 *Test events in Experiment 1 by condition. After familiarization, each infant saw 3 test trials, during which Disk/Triangle (D/T) alternated with Triangle/Disk (T/D) trials. Here only D/T trials are shown. Conditions only differed in their outcome phase. Nine-month-old infants looked longer at the Shape and Color change and the Shape change conditions, than at the No change (Control) and Color change conditions. Color differences are represented as differences in luminance.*

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 on-line 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 seconds, at which point the computer turned off the stage lights, and recorded the accumulated looking time minus 2 seconds.

All experimental sessions were recorded on videotape and later rescored 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 on-line and the off-line observer was lower than 95%, a third blind observer was used (approximately 10% of the cases). If the third observer's measurements did not agree with either of the previous observers at higher than 95%, that subject was excluded from further analysis (1 infant out of the total of 72 subjects tested). Otherwise, the earlier of the two measurements was used.

Familiarization trials

Familiarization events are illustrated in Figure 1. Two objects, a red triangle and a blue disk, were used in all familiarization trials. Experiments started with an empty stage, 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 blue 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 red triangle) with its center 7 cm away from the midline of the stage in the opposite direction. For the sake of simplicity, we will call this arrangement objects in close position. The objects remained in close position for 4 seconds, 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 our example, first the red triangle moved to the right, then the blue triangle moved to the left). We will call this arrangement far position. The objects remained in this far position for 15 seconds. The trial ended by raising the curtain.

The sequence in which the object that appeared on the stage first was the blue disk was termed the Disk/Triangle sequence (D/T) (see Figure 1). During the familiarization trials this sequence was alternated with its mirror image, the Triangle/Disk sequence (T/D), where the red 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.

Test trials

Test trials started immediately after the familiarization trials and are illustrated in Figure 2. Test trials started by placing the screens one-by-one into the 'far positions' described above. In this arrangement, the edge of each screen was 5 cm away from its adjacent 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 red triangle and the blue disk, were placed one-by-one in the 'close position' in the middle of the stage and stayed there for 4 seconds, as in familiarization trials. After this, in the order of their appearance, the red triangle and the blue 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, to reveal the pair of objects that was surreptitiously brought in with the screens.

As in familiarization trials, the first object to be displayed (red triangle or blue disk) was alternated from trial to trial. The trial where the first object was the blue disk is called again the 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.

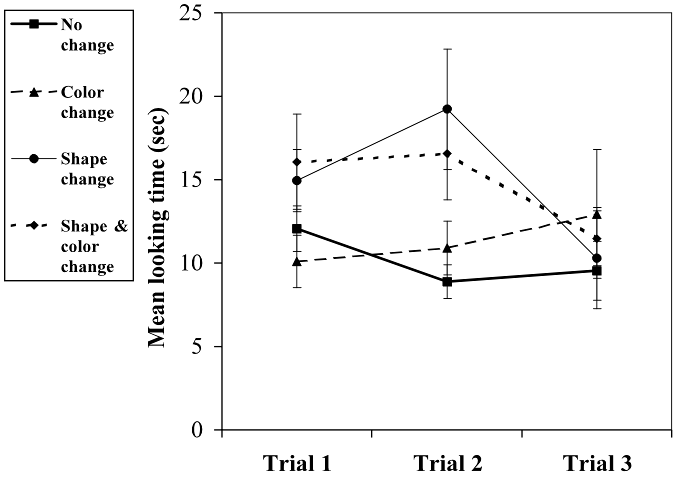
When the screens were removed, the experimenter signaled the observer, and the recording of looking time started. The trial ended when the infant looked away for 2 consecutive seconds, as determined by the on-line observer and measured by the computer. At the end of the trial, the computer turned the lights off, and the experimenter raised the curtain. Infants watched 3 consecutive test trials.

Results

Preliminary analysis showed no effect of gender, age (infants closer to 8.5 months vs. 9.5 months), first object shown (red triangle/blue 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 Figure 3. Looking times were analyzed in a repeated measures $3 \times 2 \times 2$ ANOVA with Trials (3) as a within-subject factor and Color change (2) and Shape change (2) as between-subject factors. The Color change factor was set at +1 value for the Shape and color change and Color change conditions, and was set at 0 value in the Shape change and No change (Control) conditions. The Shape change factor was set at +1 value in Shape and color change and Shape change only conditions, and was set at 0 value in Color change only and No change (Control) conditions.

There was no main effect of Trials ($F(2, 120) = 1.63$, $p = .201$, n.s.). There was no effect of Color change ($F(1, 60) < 1$, n.s.). Shape change produced significantly longer looking times ($F(1, 60) = 8.01$, $p = .006$). Color change and Shape change did not interact ($F(1, 44) < 1$, n.s.).



	Trial 1 Mean	Trial 1 SE	Trial 2 Mean	Trial 2 SE	Trial 3 Mean	Trial 3 SE
No change (Control)	12.06	1.36	8.90	1.01	9.55	1.77
Color change	10.11	1.58	10.90	1.62	12.95	3.87
Shape change	14.96	1.88	19.23	3.62	10.28	3.02
Shape & color change	16.08	2.86	16.55	2.74	11.48	1.64

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

Effect size was estimated using η^2: shape change accounted for 11.8% of the variance over all three test trials (15.2% on Trial 2 alone), while color change accounted for only 0.2%. There was a significant Trials × Shape change interaction ($F(2, 120) = 3.20$, $p = .044$). No other interactions with Trials approached significance.

Inspection of means shows that looking times in both Shape conditions fell on Trial 3, while in the other conditions looking times were approximately flat across trials (see Figure 3). The most likely explanation for this is habituation to the unexpected outcome on Trial 3. This is confirmed by Trials (2) × Shape change (2) analysis of looking times on Trials 1 and 2 alone which shows no Trials × Shape change interaction ($F(1, 60) < 1$, n.s.). (All of the main effects in this analysis were the same as in our previous analysis.)

Planned comparisons examined looking times averaged across the three trials for the experimental groups versus the control group. Because we were making multiple comparisons to a single control group, Student's t is inappropriate; therefore, we used Dunnett's t to calculate the true probabilities (Winer, Brown & Michels, 1991, p. 169). The Shape change and Shape and color change conditions both produced significantly longer looking than the No change (Control) condition ($p = .032$ and $p = .016$, respectively), while looking times in the Color change condition were not significantly different ($p = .6$, n.s.) from the No change (Control) condition.

Discussion

Experiment 1 showed that 9-month-old infants are able to use at least some featural information (shape) to identify objects. Whenever objects in given locations changed shape (but not color), infants looked reliably longer. There are two ways of thinking about this from the infants' point of view, assuming color is not represented. Either infants noticed that the shape property of a given object in a given location was unexpected or infants noticed that the objects were in unexpected locations. In other words, they might have thought that the objects miraculously changed shapes, but remained at their locations (as a frog that turns into a prince) or that they remained the same, but miraculously switched locations. We cannot tell which way the infants construed the changes. In any case, from our point of view, at this time, this is a distinction without a difference because either interpretation is consistent with the claim that the infants identified the objects by shape and by location.

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 *only* about the last-hidden object. Information about the last-hidden object remains in memory for a shorter period (4 sec) before the screen is removed than information about the first-hidden object (7 sec). Attending only to the last-hidden object would allow detection of change with a minimal memory load. In this case, Experiment 1 would be equivalent to a very simple feature-change task: an object goes behind a screen, and the screen is removed soon after, revealing an object that is different in color, shape or both.

In all multiple object experiments, the question of whether infants attend to all of the objects or just to one 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 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. In the No change (Control) condition, the screen would reveal a red triangle, while in the Shape change condition it would reveal a red disk. We decided to test the sampling hypothesis by revealing only the first-hidden object, as opposed to the last-hidden object, because this provides the stronger test.

We were primarily interested to see if we could replicate the previous results for the Shape change condition using a first-hidden only test. However, it occurred to us that removing a single screen (even the screen for the first-hidden object) might actually make the task easier. For example, now the infants have to make a judgment about a single object without the distraction of a second visible object. In case such facilitation should occur, we also included a Color change condition using a first-hidden only test. To test if removing only a single screen facilitates infants' memory, we also repeated the Color change condition with the modified procedure. We did not test infants in the third, Shape and Color condition in Experiment 2, since we did not find evidence for interaction between the Shape and the Color factors in Experiment 1.

Experiment 2

Method

Design

We repeated the Shape change, the Color change and the No change (Control) conditions, but this time we removed only one of the screens (see Figure 4 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. If infants remembered only this last-hidden object, they should not be surprised in the new Shape change condition.

Crucially, in this experiment as in Experiment 1, we alternated D/T and T/D trials. 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 through 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 50% 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. The same trial-by-trial alternation of side was also conducted for color.

Subjects

Thirty-nine healthy full-term infants (18 females, 21 males) participated in the study (age range: 8 months 15 days–9 months 15 days, mean age = 8 months 29 days, SD = 9.6 days), with 12 infants in the Shape change, 12 infants in the No change (Control) condition and 15 infants in the Color change condition. Four additional infants were excluded due to observer or experimental error (3) or fussiness (1). Parents were recruited the same way as in Experiment 1.

Apparatus, stimuli and procedure

The apparatus and stimuli were the same as in Experiment 1. Familiarization trial (see Figure 2) and test trial procedure was the same as in Experiment 1, except that for the final outcome only one of the screens was removed (for test trials, see Figure 4). Only the screen that hid the *first* object that disappeared from sight was removed. The other screen that was hiding the second object remained on the stage. The time elapsed between hiding and revealing the first object was approximately 7 seconds.

Data measuring and recording methods were the same as in Experiment 1. Inter-observer agreement was 95% or higher. No subject was excluded because of disagreement between observers.

Results

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

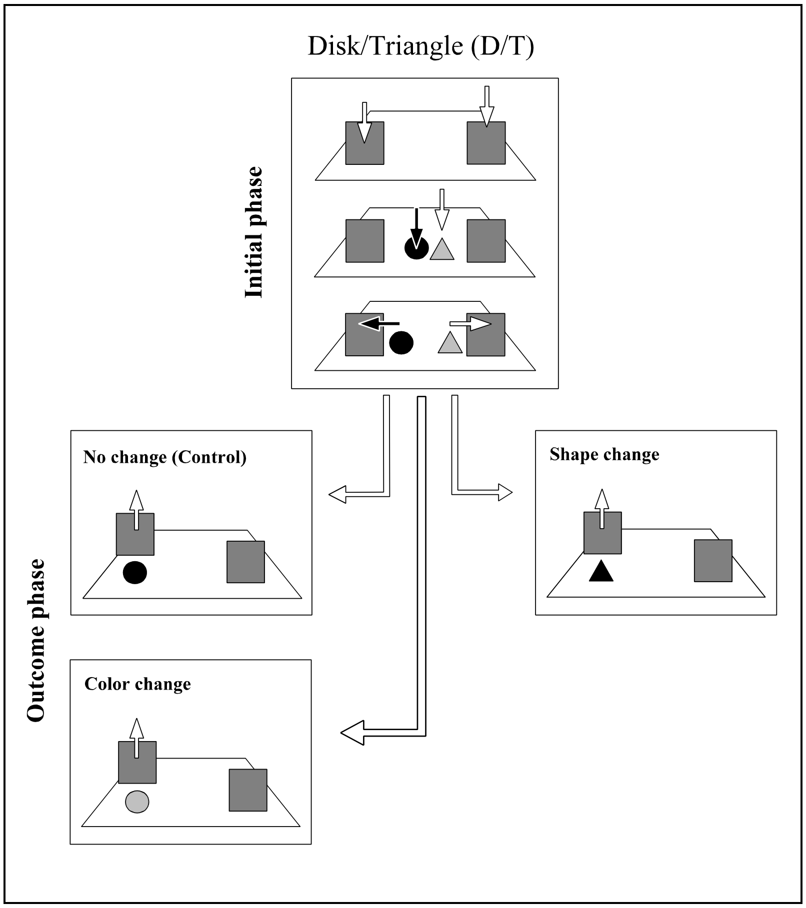


Figure 4 *Test events in Experiment 2 by condition. The first object placed on stage is indicated with a black arrow. Disk/Triangle (D/T) and Triangle/Disk (T/D) trials were alternated from trial to trial. Here only Disk/Triangle (D/T) trials are shown. Conditions only differed in their outcome phase. Nine-month-olds looked longer at the Shape change than controls. Color change infants did not look longer than controls. Color differences are represented here as differences in luminance.*

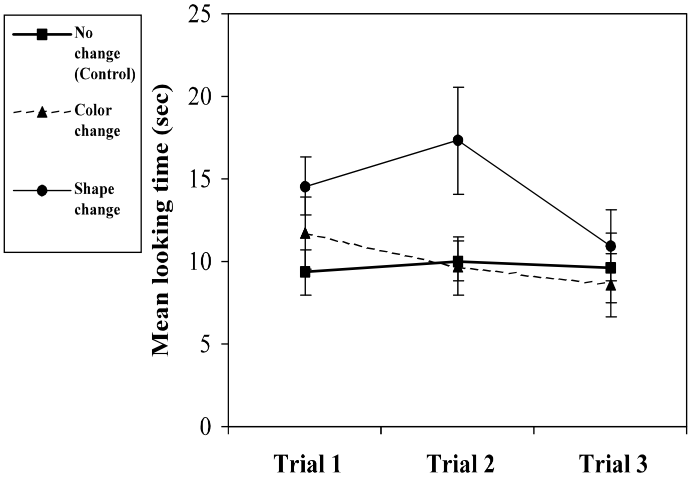
Mean looking times with standard errors by conditions and by test trials are shown in Figure 5. Looking times were analyzed in a repeated measures 3 × 3 ANOVA with Trials (3) as a within-subject factor and Condition (3) as a between-subject factor. There was no effect of Trials ($F(2, 74) = 1.64$, $p = .204$, n.s.). The main effect of Condition was significant ($F(1, 37) = 3.717$, $p = .034$).

Effect size was estimated using η^2: shape change accounted for 27.6% of the variance, while color change only accounted for 0.1% of the variance over the three test trials. No significant interaction between Trials and Condition ($F(4, 74) < 1.00$, n.s.) was found.

Planned comparisons with Dunnett's *t* compared looking times averaged over trials for the experimental groups with the control group. Again, we used the more conservative Dunnett's *t*-test instead of Student's, because we compared two experimental groups to one control group. The Shape change condition produced significantly longer looking than the No change (Control) condition ($p = .019$), while looking times in the Color change condition were not significantly different ($p = .58$, n.s.) from controls.

Discussion

Experiment 2 shows that infants can remember the shape of the object carrying the higher memory load in the two-screen paradigm. Infants should only look longer in the shape change condition in this experiment if they remembered the shape of the *first* hidden object on a given trial, because they were shown only that object in test. Figure 5 shows that infants who saw the unexpected shape outcome looked longer than infants who saw the expected outcome, replicating the results of Experiment 1. The unexpected color, however, did not



	Trial 1 Mean	Trial 1 SE	Trial 2 Mean	Trial 2 SE	Trial 3 Mean	Trial 3 SE
No change (Control)	9.35	1.35	10.02	1.21	9.60	2.10
Color change	11.72	2.20	9.72	1.72	8.56	1.89
Shape change	14.56	1.72	17.33	3.25	10.97	2.12

Figure 5 *Mean looking times in Experiment 2 in seconds by condition and trial (in seconds). Error bars represent ±1 SE of the mean.*

evoke longer looking, also replicating the results of Experiment 1.

The results with shape indicate that infants did not sample the shape of only one of the objects. It seems unlikely that infants would sample only the first-to-be-hidden object on any trial, especially since they subsequently appear to attend to the hiding of the second object. We should reasonably assume therefore that if only one of the objects is tracked it would be the last-hidden. In this case, we should have obtained no difference between shape change and control infants, ruling out this version of the sampling hypothesis.

However, there remains the possibility that infants might randomly sample one of the objects. In this case, half the infants in the present Shape change condition would have looked longer, namely, those who happened to be tracking the first-hidden object. The other half of the infants (those who happened to track only the unrevealed last-hidden object) would have no expectations for the revealed location and would look at baseline control levels. This would give longer average looking times in this group compared with controls, half of whom would have no expectations and half of whom would have expectations confirmed. This would be consistent with finding an effect of shape change in Experiment 2. However, in the shape conditions of Experiment 1, babies would have their expectations violated no matter which object they had sampled, because in that experiment both objects were revealed. Therefore, all the shape change infants in Experiment 1, as opposed to just half in Experiment 2, would contribute to the effect. We should therefore observe a larger effect size in Experiment 1 than in Experiment 2. However, the effect size was actually considerably smaller in Experiment 1 than in Experiment 2, at 11.8% versus 27.6%. This contradicts the prediction from the random sampling hypothesis. Therefore, we have good evidence that the infants represented the shape properties of both objects of the pair. The results suggest then that distinctive shape featural information was bound to both ORs.

The negative results with color replicate the results of Experiment 1. It appears our 9-month-olds did not use the particular color information that we provided to identify the objects in our task.

General discussion

We consider first the implications of our findings for our cognitive model, and then we place the model within a neuroscientific framework.

Leslie *et al.* (1998) drew a distinction between information that is used to establish an object representation, that is, to individuate objects, and information that finds its way into or is stored with the object representation. If property information is stored in the object representation, then it will be available later for deciding whether an object is one that has been encountered before (identification). The present results provide some of the first evidence that infants as young as 9 months can identify objects by feature. The effects obtained in Experiments 1 and 2 were entirely due to the shape feature; there was no evidence in either study for infants using color to identify the objects. The results are consistent with the idea that, when infants establish a representation for an object (individuation), featural information may optionally be entered into or bound with the object representation (OR). It appears that under the conditions of the present experiment, namely, hiding each of two objects behind distinct and physically separate screens, infants can and will bind shape, but not color, information to the ORs.

We cannot reach a strong conclusion regarding infants' failure to bind color because, when comparing differences across the dimensions of shape and chromaticity, it is hard to know whether one has equated the magnitude or salience of the difference. It is possible that infants might use an extremely salient color difference for identification. However, we do note that a similar discrepancy between color and shape for object identification was found by Tremoulet *et al.* (2000) in 12-month-olds. In that case, it was possible to show that the color difference was not ignored and was indeed great enough to drive individuation, thus addressing concerns about dimensionality and salience. In the present experiment, we cannot draw such a strong conclusion because infants could individuate objects on the basis of the distinct locations they were seen to occupy. Nevertheless, given that the same color differences were used as in the object identification experiments in Tremoulet *et al.* (2000), the present findings are consistent with shape and color information having different roles in identification. If so, this finding can be extended to identification by location.

In our task, infants could individuate the objects by noting that they occupied distinct locations both before and after hiding. Xu and Carey (1996) drew attention to the difference between individuating on the basis of spatiotemporal information (location over time) and individuating on the basis of property information (e.g. features). Leslie *et al.* (1998) drew a further distinction between individuation and identification. Putting these distinctions together, one can ask separately about the basis for individuation and identification. For example, suppose infants of 9 months will individuate only by location, but not by feature; nevertheless, it is legitimate to go on to ask whether such a 9-month-old who has individuated objects by location, can subsequently identify the objects by feature. The present results show that this is indeed possible.

The second experiment replicated the results of Experiment 1 and extended them to show that infants probably attend to and remember both objects in the pair. Infants remembered the shape of the first-hidden object, even though their attention was distracted away from that object while the second object was moved and hidden. Presumably, they had to maintain information about the first-hidden object in working memory. Infants had reliable memories for shapes of objects in specific locations that lasted for up to 7 seconds. We do not know how much longer such memory would persist.

The performance of the infants seems impressive when one considers that we employed an 'event mapping' task, which is often considered demanding (Wilcox & Baillargeon, 1998).[1] A further reason for being impressed was that we alternated the sidedness of the objects from trial to trial. This was an essential feature of our design. Suppose we had simply presented the same shaped object 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. We thus force infants to pay attention on each trial to which object went behind which screen. Only then 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.

Our results are also congruent with Wilcox's results (Wilcox, 1999) on the availability of different featural properties for individuation. She showed that infants can use shape and size at 4.5 months, texture at 7.5 months and color only at 11.5 months. However, we would like to stress again the distinction between individuation and identification and their possibly different developmental courses (see above, Tremoulet *et al.*, 2000, for color information, and see also Wilcox & Schweinle, 2002).

Our tentative functional model of identification and individuation processes is shown in Figure 6. Low-level

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[1] Wilcox and Baillargeon (1998) found only one instance in which young infants individuated by feature in an event mapping task. This was where the object had a simplified trajectory with a single non-repeated motion without reversal of direction.

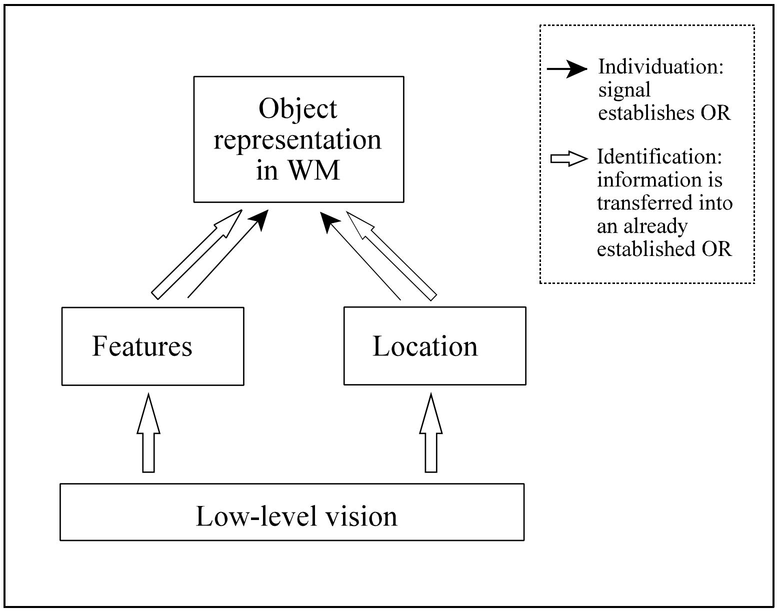

Figure 6 *Schematic diagram of hypothesized cognitive processes. Low-level vision provides information about edges, surfaces, reflectance and retinotopic coordinates. This information is further processed and representations of features (shape, color, real size, etc.) and locations in an allocentric (object-centered) reference frame are established. This information can be used merely to set up an object representation in working memory (individuation) or alternatively, it can be bound to the newly created representation and be available later to re-identify the object (identification). The two processes are independent as are the two possible routes via features vs. locations. WM – working memory; OR – object representation.*

visual processing (presumably in the primary visual cortex, V1) yields information about basic perceptual attributes, such as spatial frequency, orientation, motion, color and contrast. This information is further processed in two parallel mechanisms: one that extracts the features, 'what', and one that analyzes the locations of objects in the scene, 'where'. Information arising from featural analysis or from occupied location analysis may lead to the establishment of ORs (individuation). In this case, featural and spatial coordinate information may then be entered into the OR and be available for later use (identification). Four distinct functional processes are therefore possible: individuation by feature, individuation by location, identification by feature and identification by location. Our experiments reported here give evidence for identification by feature at 9 months, where individuation by location was possible because we presented the objects in different locations. Our results also establish a stronger finding, namely, that 9-month-olds can integrate identification-by-feature and identification-by-location. Our infants did not merely expect a triangle and a disk; they expected each to be in a particular location. We could not have shown this using a single screen paradigm. Whether infants younger than 9 months are also able to use features to identify objects by location remains an open question.

There are some similarities between our model and one outlined by Prazdny (1980). However, the similarities are superficial. Prazdny's computational model was based on Bower's claims (e.g. Bower, 1974) that infants between 12 and 20 weeks believe that an object that goes from stationary to moving (or from moving to stationary) becomes a new object. This idea has garnered little support. However, Bower's theory made the then novel suggestion that object representation is spatiotemporally based and independent of featural information. Featural integration comes later in development, and, in Prazdny's treatment of these ideas, later in on-line processing. Both these authors developed their ideas prior to Ungerleider and Mishkin's (1982) 'what-where' theory of cortical processing. Mareschal, Plunkett and Harris (1999) propose a model of object search in infants that embodies the dual route principle: there is 'an early dissociation between infants' ability to use surface features (e.g. colour) and spatial-temporal features' (p. 306) in regard to hidden objects. Our results suggest that the dissociation with respect to color remains at 9 months and, according to Tremoulet *et al.* (2000), even at 12 months.

Although our cognitive model has been developed on the basis of behavioral findings, it is both possible and desirable to attempt to relate it to the development of underlying neural systems. Visual object recognition and object localization are thought to depend on two relatively separate anatomical systems in the human brain. Recognition depends on the ventral visual stream, a cortical pathway that starts from the occipital lobe and continues to the temporal lobe – the so-called 'what' pathway. Localization depends on the dorsal visual stream – the so-called 'where' pathway. This pathway also originates from the occipital lobe, but continues toward the parietal lobe (for the pioneering study on primates, see Ungerleider & Mishkin, 1982; see also Baizer, Ungerleider & Desimone, 1991; for human imaging studies, see Haxby, Grady, Horwitz, Ungerleider, Mishkin, Carson, Herscovitch, Schapiro & Rapoport, 1991; Kohler, Kapur, Moscovitch, Winocur & Houle, 1995; for a recent reinterpretation of the classic model: Milner & Goodale, 1995, in a developmental framework: Atkinson, 2000). Leslie *et al.* (1998) hypothesized that the process of setting up ORs was driven primarily by location and that the integration of featural information would occur developmentally later. Our present results suggest that the integration of 'what' and 'where' information takes place at earlier ages than that originally hypothesized by Leslie and colleagues.

What part of ventral stream processing might be responsible for the object identification exhibited by the infants in our study? A recent study by Baker and his colleagues (Baker, Keysers, Jellema, Wicker & Perrett, 2001) has demonstrated that some neurons in a specific part of the temporal cortex in macaques respond to objects that gradually become occluded. This response is maintained for up to 11 seconds following complete occlusion. In most of the neurophysiological studies on working memory, objects disappear suddenly on a computer screen. Baker *et al.* used natural, progressive occlusion of 3D objects, which is similar to displays used in developmental studies.

It has long been known from single cell studies that the inferotemporal cortex is involved in visual object working memory (Baylis & Rolls, 1987; Miyashita & Chang, 1988; Miller, Li & Desimone, 1991, 1993). In monkeys, visual recognition memory is most commonly measured by 'delayed matching to sample' and 'delayed non-matching to sample' tasks. Many neurons in the temporal cortex have working memory-related responses. These responses have several distinct types (Desimone, 1996). One of these is response enhancement: if the item matches the previously seen sample, these neurons increase their firing rate (Suzuki, 1999; Suzuki, Miller & Desimone, 1997). While other types of memory-related responses of the temporal cortex were shown to be temporary (Miller *et al.*, 1993), that is, intervening items reset the activity, response enhancement is not sensitive to the nulling effect of new perceptual stimuli and it might have a significant role in signaling that '*this* object is the one that went behind *that* screen'. For a more detailed version of the proposed neurophysiological hypothesis, see Káldy (in prep.).

Our studies showed that 9-month-old infants are capable of tracking what object (as identified by shape) went where (as defined by separate screen locations). The infants' OR can therefore integrate featural information with location information. We conclude that our data present evidence for functional integration between the object recognition and the object localization systems in humans by 9 months of age.

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