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Cognitive Development 15 (2000) 499–522

COGNITIVE DEVELOPMENT

Infant individuation and identification of objects

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Received 1 April 2000; accepted 1 January 2001

Abstract

Recent studies of the infant's object concept have focused on the role of property information in individuation. We draw a distinction between individuation and identification. By individuation, we mean the setting up of an object representation (OR). By identification, we mean using the information stored in an OR to decide which, if any, previously individuated object is presently encountered. We investigate this distinction in experiments with 12-month-old infants. We find that for infants of this age, a shape difference between two objects has a large effect on both individuation and identification. However, a color difference between two objects has a large effect on individuation, but little or no effect on identification. This suggests that, somewhat surprisingly, information used to establish an OR may not always be incorporated into that representation.

Keywords: Infants; Objects; Individuation; Identification

1. Introduction

Young infants are sensitive to a range of object properties, including permanence, volume, solidity, spatiotemporal continuity, causality, and numerosity (Baillargeon, 1986, 1987; Baillargeon, Spelke, & Wasserman, 1985; Leslie

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PII: S0885-2014(01)00038-7

& Keeble, 1987; Piaget, 1955; Spelke, 1988, 1994; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Wynn, 1992). However, infants do not always make adult-like judgments based upon differences in objects' features (Simon, Hespos, & Rochat, 1995; Wilcox & Baillargeon, 1998; Xu & Carey, 1996). In one study (Xu & Carey, 1996), 10-month-olds were familiarized with a display in which a yellow rubber 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. When the screen was removed to show either both objects (control) or only one of the objects (unexpected), the infants showed only baseline looking to the unexpected outcome, suggesting that they failed to register the presence of two objects behind the screen when presented sequentially. These infants showed different from baseline looking to the unexpected single object display only if they had an opportunity to see both objects simultaneously. Xu and Carey's (1996) 10-month infants individuated the objects on the basis of their distinct locations, but not on the basis of their featural differences. By 12 months of age, Xu and Carey's infants expected two objects behind the screen under both sequential and simultaneous presentation conditions. However, Wilcox and Baillargeon (1998) have found that younger infants (4–9 months) may use featural information to individuate objects under certain simplified presentation conditions (see also Wilcox, 1999).

When two objects differing only in shape or only in color are sequentially pulled out from and returned behind a screen, adults expect not only that two objects will be behind the screen (individuation), but also that the objects will have the appropriate shapes and colors (identity). Xu and Carey's (1996) results with 12-month-olds provide evidence only for the first of these expectations (individuation); they do not provide any direct evidence for the second (identification). Following sequential presentation of a duck and a truck, Xu and Carey's 12-month-olds expected two things behind the screen, but it is not possible to tell if their expectation was for 'a duck and a truck' as opposed to merely 'two things' (of indeterminate identity). To check this possibility, further conditions are required in which the screen reveals two ducks or two trucks. If infants expect simply 'two things,' then they will look only as long in these further conditions as in the original control condition. However, if they expect exactly 'a duck and a truck,' then these new conditions should be unexpected and attract longer looking.

Similar remarks apply to the studies of Wilcox and Baillargeon (1998). Those authors found that younger infants looked longer when a ball entered behind a narrow screen and a cube emerged than when a ball both entered and emerged. Such a finding may suggest that the infants inferred from the shape-featural differences between the objects that two distinct objects were involved. However, it remains an open question whether the infants, shown ball entering and cube leaving, expect a ball or merely some (indeterminate) thing to remain behind the screen. This could be tested by dropping the screen to reveal either a ball or a cube and seeing whether the cube attracts longer looking.

Why is testing for identification, as well as individuation, important? The answer, following Leslie et al. (1998), has to do with the nature of the infant object representation (OR). There are various kinds of information — e.g., spatiotemporal continuity, shape, texture, kind, etc. — whose efficacy in driving individuation has been tested. Such tests probe the processes that establish the OR and ask, What kinds of information lead to the setting up of an OR? This question is investigated by asking *how many* ORs the infant establishes for a given stimulus display (e.g., Kellman & Spelke, 1983; Spelke, Kestenbaum, Simons, & Wein, 1995; Wynn, 1992; Xu & Carey, 1996). But, for identification, we ask a different question, namely, Given that an OR has been established, what information *must* it contain? Must an OR contain information describing the shape, the color, and the kind of the object it designates? Or must the OR contain *only* the information about the object that led to its establishment? Or is it possible for an OR *not* to contain the information that established it? These questions are just as fundamental to the nature of OR as questions about individuation.

Descriptive information contained in an OR is often required for later identification. Suppose, e.g., that an OR has been set up for an object behind a screen, but that it contains no shape information. The infant will expect an object to be behind the screen, but he will not expect that object to have any specific shape.

One way to test for identification information is for the experimenter surreptitiously to substitute an object of a different shape behind the screen. If the OR does not contain shape information, then the infant will be blind to this change. However, the experimenter must be careful that the substitute object has a shape that is familiar to the infant; otherwise, the infant may respond simply because the shape is novel rather than because he did not expect *that* object to have *that* shape. Only by substituting a familiarized but wrong-for-that-object shape does the experimenter address object identification rather than simply memory for shape.

Whereas there have been a number of studies recently that address how ORs are established by infants (individuation), little is known about the nature of the information contained in the resulting OR (identification). Also, little is known about the relation between object individuation and identification. The present paper addresses the last two questions.

Following Xu and Carey (1996), we hypothesized that 12-month-old infants who individuated two objects presented sequentially by noting a shape difference would expect not simply two objects but two objects *with the familiarized shapes* when the screen was removed. We expected the infants to try to identify each of the objects by shape. We tested this by familiarizing infants with a triangle and a disk removed from and returned behind a screen one at a time. Following familiarization, the screen was removed to reveal either (expected) the two familiar objects (disk and triangle) or (unexpected) two same shape objects (two disks or two triangles). If infants identify, as well as individuate, the objects by shape, then infants will look longer at the unexpected same-shape outcomes, even though the particular shapes involved are familiar.

2. Experiment 1

2.1. Method

2.1.1. Design

Infants in the Control condition were familiarized to a disk and a triangle. The objects were shown to the babies one at a time by drawing each from behind a screen then returning it before displaying the other object. Following three familiarization trials, three test trials were given. In test trials, the screen revealed the same two objects. In the Identification-by-Shape condition, infants were familiarized again to the disk and triangle displayed sequentially. In test trials, the screen revealed either two disks or two triangles, counterbalanced across subjects (see Fig. 1).

2.1.2. Subjects

Twenty-four full-term infants aged between 11 months and 12 days and 13 months and 10 days (mean age 11 months and 29 days) with approximately equal numbers of males and females were randomly assigned to one of two conditions, 12 babies per condition. A further two infants were tested but rejected, one due to fussing, and one because of experimenter error.

2.1.3. Materials

A pair of identical wooden disks, 10.5 cm in diameter and 0.9 cm thick, was used together with a pair of identical wooden triangles, 11.5 cm high with base 10.5×0.9 cm^2 thick. All objects were painted bright blue. A white cardboard screen 21×24 cm^2 was also used. These objects were manipulated by an experimenter wearing a black glove.

2.1.4. Procedure

Subjects sat on parents' laps at a distance of approximately 0.75 m from the middle of a three-sided grey wooded stage, 49 cm (tall) $\times$ 97 cm (wide) $\times$ 64 cm (deep), illuminated by four concealed lamps. The room was illuminated by infrared lamps. Parents were asked to close their eyes during test trials, and to refrain from talking to the infant except to give comfort. The experimenter was concealed by a grey curtain at the back of the stage, so that only his/her gloved hand was visible. The stage was illuminated by four 20-W lamps. A computer signal turned the lights on to start a trial and turned them off again to end a trial. All infants were videotaped and a hidden observer, blind to condition, timed the infants' looks at the displays from a black and white head-and-shoulders *en face* video image.

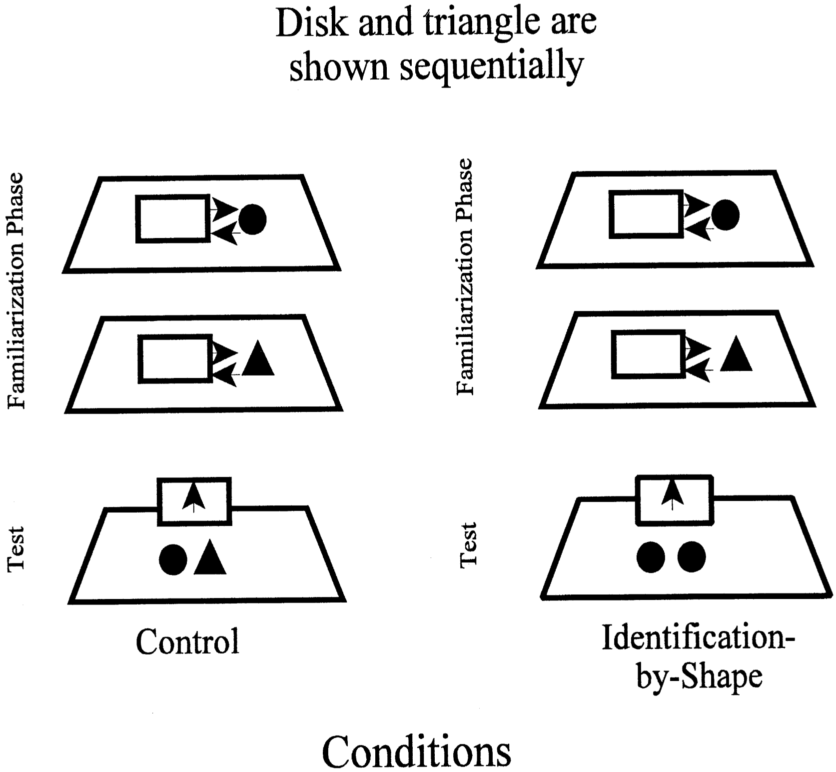


Fig. 1. Experiment 1 began with three familiarization trials (familiarization phase above) in which a triangle and a disk were alternately removed from and then placed back behind a screen. The objects were visible each time for about 2 s each, but were never visible simultaneously. During each familiarization trial, each object was presented twice. In test, each object was presented once as before, then the screen was removed to reveal two objects. In the Control condition, the screen revealed the previously seen objects. In the Identification-by-Shape condition, the screen revealed two identical objects (either two disks or two triangles). The shape of the first seen object, the positions of the objects when revealed, and the side of the unexpected object were counterbalanced across subjects.

The experiment began when the stage lights came on, revealing an empty stage with only a screen turned sideways so that the baby could see that there was nothing behind it. The experimenter's black gloved hand then entered through the back curtain, moved the screen to the middle of the stage, and turned it orthogonal to the infant's line of sight. The lights were turned off and then the experimenter introduced the objects through the back curtain. (Because the room was very dark, and the experimenter's hand and the objects were always occluded from the infant by the screen, the objects were not visible while being added.) Three identical familiarization trials were presented. Each of these trials began when the lights came on and the experimenter grasped one of the objects behind the screen. The experimenter's right arm extended onto the stage through the gap in the back curtain; thus, it was initially occluded from the infant's view. The experimenter took 1 s to move the first object about 45 cm, placing it next to the screen. During movement, the lower forearm, covered in a black glove, was visible, as well as the object. After placing the object in view, the experimenter rested his/her hand directly behind the object on the stage, leaving the object stationary for about 2 s. Then he/she returned the object behind screen, again taking 1 s to move it approximately 45 cm. Next, the experimenter used the same method to pull out the second object, display it, and return it. This entire sequence was repeated once and then the lights were turned out, completing a familiarization trial. Thus, each object was stationary and visible for about 2 s per display, for a total of 4 s per familiarization trial. Timing of the presentation was regulated by a metronome beating every second.

Following the three familiarization trials, three test trials were given. In each test trial, the two objects used during familiarization trials were sequentially displayed, as during the first half of a familiarization trial, and then the screen was moved to the side and rotated by 90° to reveal the outcomes (see Fig. 1). On Identification-by-Shape trials, one of the original objects was surreptitiously replaced with another that differed in shape: the experimenter used his/her left hand to add a third object and to remove one of the familiarized objects through the gap in the back curtain, which was occluded by the screen. In the Control trial, a novel object was added through the gap and then removed again to ensure that the mechanics were the same in both conditions. Timing of looking, recorded by computer, began immediately after the screen was moved aside on test trials. Trials ended when infants had looked continuously for a minimum of 1.5 s and then looked away continuously for 2 s. The left–right positions of the objects were counterbalanced across test trials. In the Identification-by-Shape condition, the shape of the object last visible immediately prior to removal of the screen was also counterbalanced.

2.2. Results

In-session scoring was later checked by a second observer who produced a second measure of a subject's looking time by using a videotape showing the infant's behavior during an experimental session. The second observer was always blind to condition. Inter-observer agreement was computed by subtracting the difference between the first and second observers' looking time measures and dividing by the first observer's measure; it averaged 92%. There were no statistical effects of gender, shape of object first moved, left–right position of changed object, or shape of changed object. Looking times averaged across the three test trials for each condition are shown in Fig. 2. Infants in the Control condition looked for a mean of 7.5 s and in the Identification-by-Shape condition for 11.7 s. Looking times were analyzed by ANOVA with factors Trials (3) $\times$ Conditions (2). Trials was a significant main effect [$F(1,22) = 14.52$,

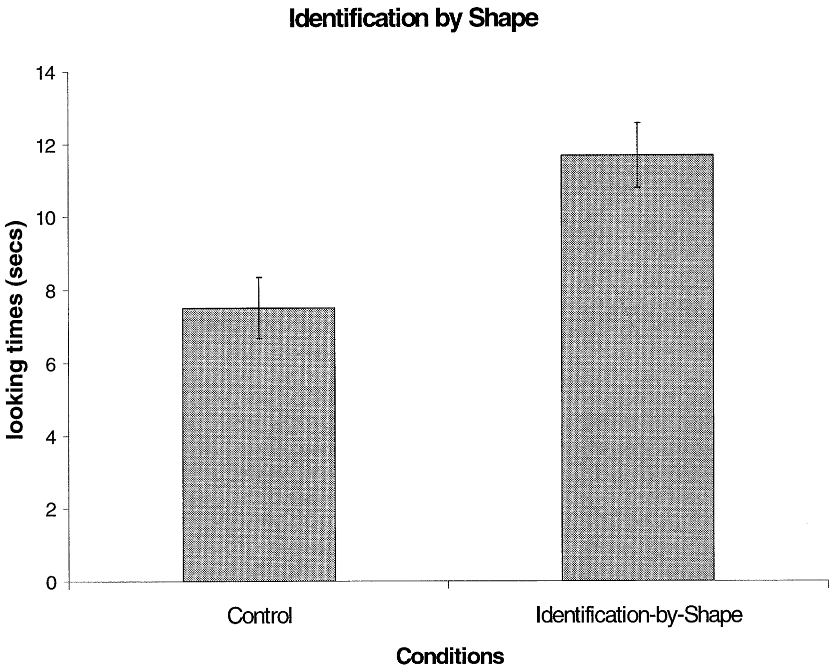


Fig. 2. Results of Experiment 1.

$P = .001$] with no Trials × Conditions interaction [$F(1,22) = 0.5$, ns] reflecting a uniform decline in looking across trials. Conditions produced a highly significant effect [$F(1,22) = 11.7$, $P = .002$]. Effect size was calculated using η^2 which showed that Condition accounted for 34.6% of the variance.

2.3. Discussion

Our results show that when sequentially shown two objects that differ in shape (disk vs. triangle), our 12-month-old infants looked longer when the screen revealed two identical objects (e.g., two disks) than when it revealed the two original objects. By 12 months, infants will not only use property information to individuate objects when spatiotemporal information is ambiguous, but will also use that information, at least shape information, to identify the objects involved. Xu and Carey's (1996) theoretical claims require the infant to expect not simply two things behind the screen but two things with determinate, i.e., the familiarized, identities. Their original studies failed to include the appropriate conditions to test this. However, our first experiment provides an appropriate test and suggests that shape can drive object identification at 12 months.

In Experiment 2, we test whether color can also drive object identification at this age.

3. Experiment 2

3.1. Method

3.1.1. Design

Infants in the Control condition were familiarized to a blue disk and a red disk. The objects were shown to the babies one at a time by drawing each from behind a screen then returning it before displaying the other object. Following three familiarization trials, three test trials were given. In test trials, the screen revealed the same two objects. In the Identification-by-Color condition, infants were familiarized again to the red and blue disks displayed sequentially. In test trials, the screen revealed either two red disks or two blue disks, counterbalanced across subjects (see Fig. 3).

3.1.2. Subjects

Twenty-four full-term infants aged between 11 months and 16 days and 12 months and 28 days (mean age 12 months and 6 days) with approximately equal numbers of males and females were randomly assigned to one of two conditions, 12 babies per condition. A further two infants were tested but rejected, both because of fussing.

3.1.3. Materials

A pair of wooden disks, 10.5 cm in diameter and 0.9 cm thick, were used, one painted bright red, the other painted bright blue. Otherwise, materials were the same as in Experiment 1.

3.1.4. Procedure

The procedure was the same as in Experiment 1. The stimulus displays used are illustrated in Fig. 3.

3.2. Results

Inter-observer agreement, calculated in the same way as in Experiment 1, averaged 90%. There were no statistical effects of gender, color of object first moved, left–right position of changed object, or color of changed object. Looking times averaged across the three test trials for each condition are shown in Fig. 4. Infants in the Control condition looked for a mean of 8.5 s and in the Identification-by-Color condition for 9.7 s. Looking times were analyzed by ANOVA with factors Trials (3) $\times$ Conditions (2). Trials was not significant as a

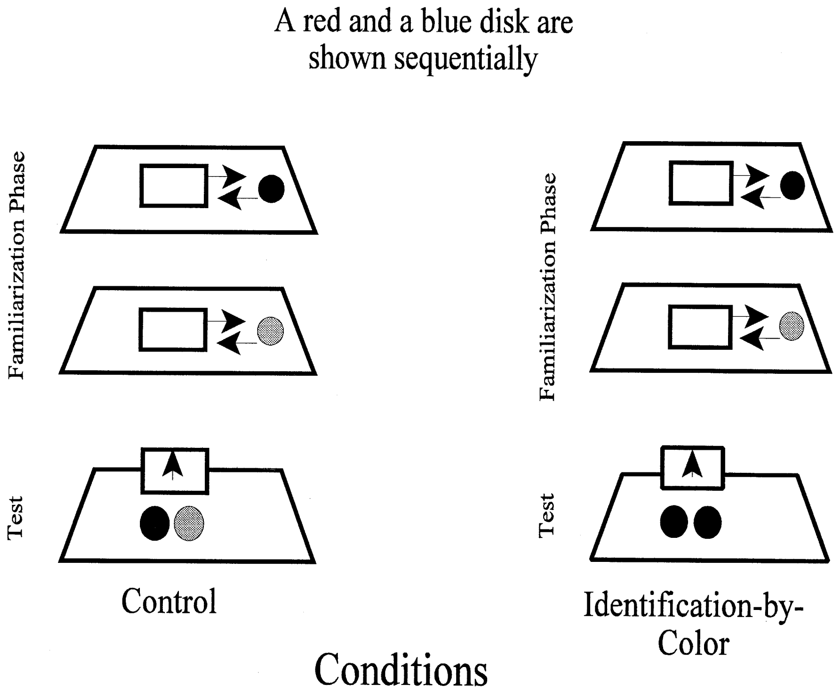


Fig. 3. Experiment 2 began with three familiarization trials in which two differently colored disks were alternately removed from and then placed back behind a screen. The procedure was the same as in Experiment 1. In the Control condition, the screen revealed the previously seen disks. In the Identification-by-Color condition, the screen revealed one of the previously seen disks plus another of the same color. The color of the first seen object and positions of the objects revealed (in the Control condition) were counterbalanced across subjects.

main effect [$F(2,44) = 1.85$, ns] or in interaction with conditions [$F(2.44) = 1.4$, ns]. Conditions main effect was not significant [$F(1,22) = 0.65$, ns]. Effect size of condition was calculated as η^2: the effect of color on identification accounted for only 2.9% of the variance.

3.3. Discussion

When 12-month-olds were familiarized sequentially with two objects which differed only in color (e.g. red vs. blue), they did not subsequently look longer when the screen revealed two red (or two blue) objects. The fact that subjects in the Identification-by-Color condition did not look longer than those in the Control condition suggests that our infants failed to attend to the colors of the objects behind the screen. One possibility is that 12-month-olds completely ignore color. Infants of this age have normal color discrimination (Bornstein, Kessen, & Weiskopf, 1976) and, under some circumstances, 9-month-olds find

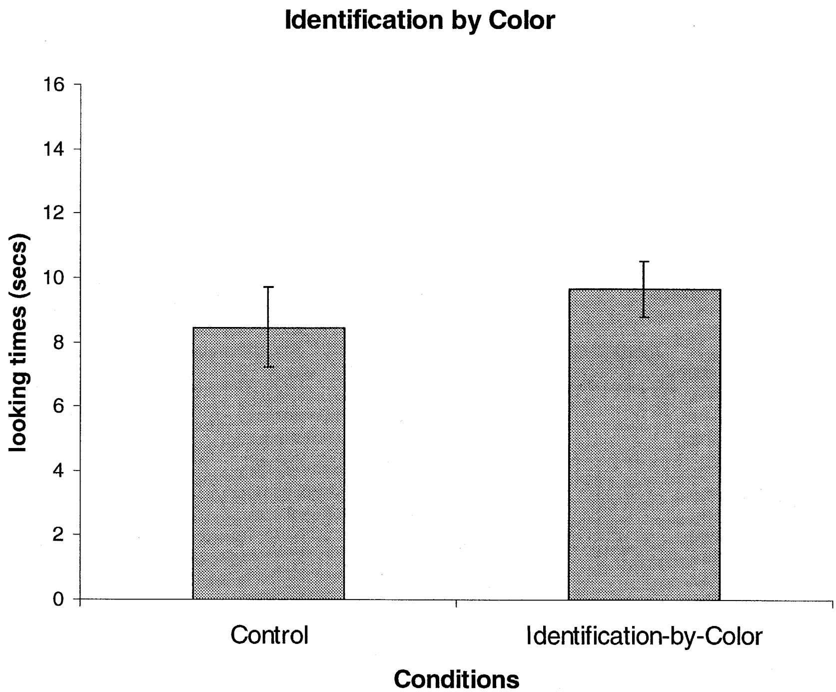


Fig. 4. Results from Experiment 2.

color properties more salient than shape (Coldren & Colombo, 1994). It would therefore be surprising if our 12-month-olds had simply failed to attend the color differences. Another possibility is that color differences *are* detected and, in fact, signal distinct objects; however, the information about the color does not enter the OR. If so, this information would not be available for identification. Given this possibility, we were unwilling simply to assume that failure to use color for identification necessarily entails that color cannot be used for individuation. Instead, we tested this possibility experimentally by comparing the effect of color on individuation to its effect on identification.

Our question was, Does color have an equally small effect on individuation as it does on identification? At first blush, it seems it *must*. Consider what happens when two differently colored, but otherwise identical, objects are presented alternately and sequentially. Each object is removed individually from behind a screen, displayed briefly, then returned behind the screen before the next object is removed, displayed, and then returned. The two objects are never seen together. If the infant is to distinguish, and thus individuate, the objects across presentations, he/she must retain color information from the first presentation in order to notice that the object presented second has a different color from the object presented first; he/she must then, on the third presentation (when the first object is shown again), recognize that this shows the same color as the first presentation and is therefore (probably) the same object as the one seen on the first presentation; he/she must again retain the color information through the fourth presentation to recognize this is the same color seen in the second presentation and is therefore (probably) the same object as that seen on the second presentation; and so on throughout the alternating trials. Therefore, individuating the objects by color presupposes identifying the objects by color. QED.

The above commonsense analysis appears compelling. However, it is not decisive. It is conceivable that featural information may signal for the establishment of an OR, yet remain in a different part of the processing system from the OR, and not enter into the OR. For example, suppose, when our red disk first appears, that the infant's visual system registers the novelty of the color information and that the apparent novelty signals that a new OR should be constructed in working memory. Suppose also that the color information responsible for the individuation decision remains stored in the visual system and does not attach itself to the OR in working memory. Without the attachment or binding of the color feature information to the OR, it will not be available for *object* identification purposes. But, because it remains in the visual system, it is available for *color* identification purposes. Subsequently, when the green disk appears, a second novel color signal from the visual system is generated. This triggers the creation of a second OR in working memory, again without any color information being bound to the OR. So now, working memory contains two ORs, neither of which contains information specifying which color directed its creation. The commonsense analysis of the previous paragraph implicitly assumes that any information which leads to the establishment of a representation must *necessarily* be displayed by that representation. But, clearly, that is not the case.

The speculative model above shows that individuation by color does not *logically* entail identification by color. But is there any reason to take this possibility seriously? One reason is that similar processes are thought to play a role in adult visual attention. For example, Treisman has distinguished between 'feature maps' and 'object files' (Treisman, 1988; Kahneman, Treisman, & Gibbs, 1992). The key distinction in Treisman's model is that featural information may be registered across a set of different 'feature maps' without being gathered together in an object file. It is only when this information has been entered into an object file that the perceiver is able to identify which object carries which features. Sagi and Julesz (1985) report that subjects are much faster at discriminating and detecting targets that differ in only a single feature than they are at identifying what that feature is. The dissociability of individuation and identification processes is also predicted by the FINST theory of multiple object tracking (Pylyshyn, 1989, 1994). This prediction has recently been confirmed in studies of multiple object tracking through occlusion in which adults track the locations of a set of objects but not their identifying features (Scholl & Pylyshyn, 1999). Leslie, Xu, Tremoulet, and Scholl (1998) and Scholl and Leslie (1999) have argued that similar processes play an important role in the infant's developing object concept.

Experiment 3 was designed to compare the effect of color on individuation with its effect on identification. In case infants require more time to encode color information than we provided in Experiment 2, we increased the time of each object presentation from around 2 s to around 3.5 s.

4. Experiment 3

4.1. Method

4.1.1. Design

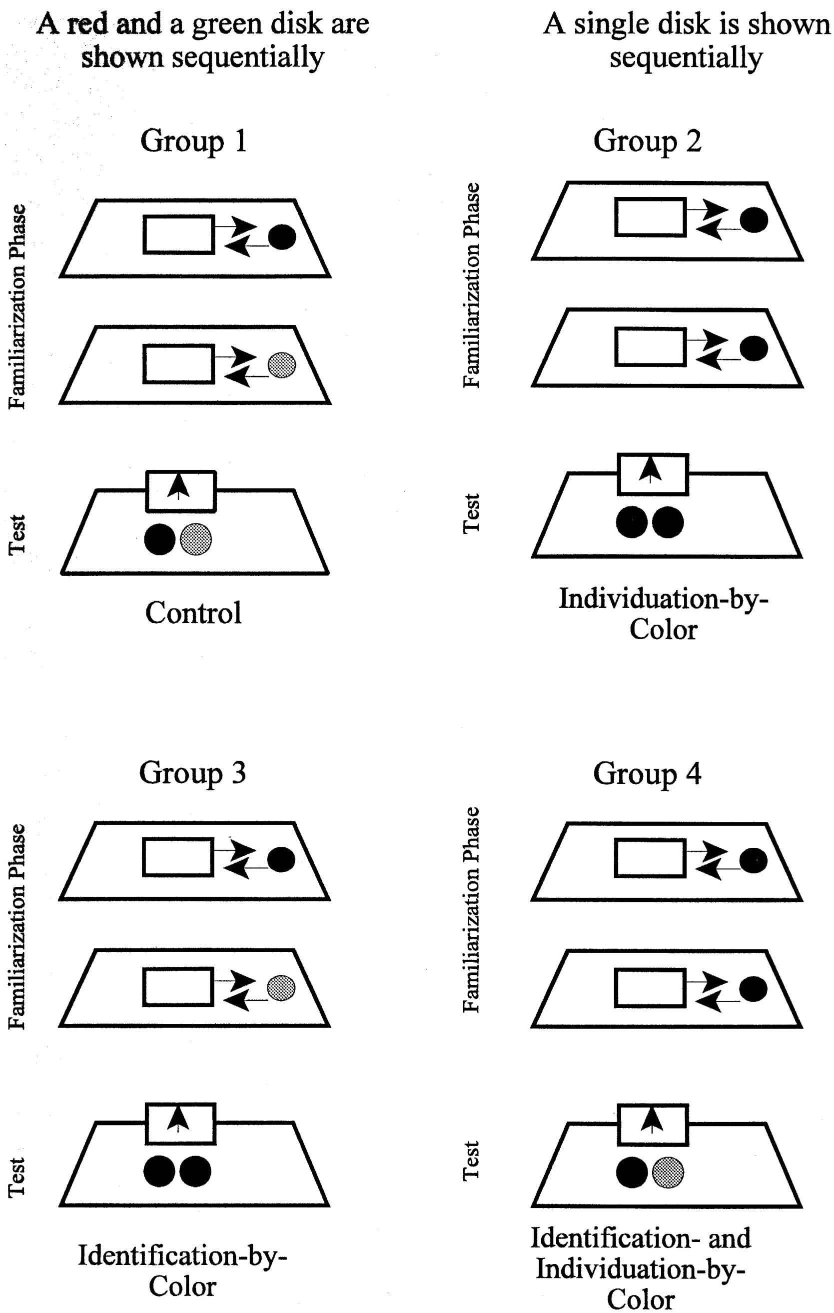
There were four conditions: Control, Individuation-by-Color, Identification-by-Color, and Identification-and-Individuation-by-Color (Fig. 5).

In the Control (Group 1) and Identification-by-Color (Group 3) conditions, infants were familiarized with alternating red and green disks presented one at a time, sequentially. Following familiarization, in the Control condition, the screen was removed to reveal one red and one green disk. In the Identification-by-Color condition, the screen revealed two same-colored disks (either two red or two green). Thus, in the Identification-by-Color condition, the color of one of the disks changed between familiarization and test. Longer looking in this condition would reflect infants' attention to the changed identity of one of the objects. These first two conditions were the same as the two conditions used in Experiment 2.

In the Individuation-by-Color (Group 2) and Identification-and-Individuation-by-Color (Group 4) conditions, infants were familiarized with a 'single' object of constant color (either red or green) pulled out from and returned back behind the screen. To ensure that the mechanics of presentation were the same across these and the distinct object conditions, we alternated two objects that were identical in every respect including color. Since the objects could not be individuated, it appeared that the same object was presented repeatedly. Infants should therefore expect only a single object to be behind the screen.

Fig. 5. Experiment 3 began with three familiarization trials in which two differently colored disks (left panels) or two identical disks (right panels) were alternately removed from and then placed back behind a screen. When identical disks were shown sequentially, we assumed infants would believe they were viewing the same single object repeatedly and expect only one object behind the screen. Test displays were crossed with familiarization displays so that half the groups saw expected colors (top panels) and half saw unexpected colors (bottom panels). The procedure was the same as in Experiments 1 and 2, except that the objects were each visible during each presentation for about 3.5 s, instead of 2 s. In the Control condition, the screen revealed the previously seen disks. In the Individuation-by-Color condition, the screen revealed the previously seen disks (two disks of the same color). In the Identification-by-Color condition, the screen revealed one of the previously seen disks plus another of the same color. In the Identification-and-Individuation-by-Color condition, the screen revealed one of the previously seen disks plus another disk of a different color. The color of the first seen object, the positions of the objects revealed, and the side of the unexpected object were counterbalanced across subjects.

In the test phase of the Individuation-by-Color condition, the screen revealed an unexpected number of disks (two), namely, those used in familiarization. In



this condition, no novel color was presented during test. Therefore, longer looking times relative to Control should be a response to an unexpected number of objects.

In the test phase of the Identification-and-Individuation-by-Color condition, the screen also revealed an unexpected number of disks (two), but this time one disk was red and the other was green. Recall that during familiarization we alternated two identically colored disks. Thus, in the test phase of this final condition, both an unexpected number of objects and a novel color were presented.

4.1.2. Subjects

Forty-eight full-term infants (26 female, 22 male) with mean age of 12 months and 7 days (range 11 months and 16 days to 13 months and 1 day) were tested and assigned randomly to conditions with 12 subjects per condition. Nine further subjects were excluded because of sleepiness/distress.

4.1.3. Materials

Two pairs of identical wooden disks, the first pair painted bright red and the second pair bright green, were used in all trials. The disks were 10.5 cm in diameter and 0.9 cm thick. In addition, a white posterboard screen 34×33 cm^2, with the front face covered by orange construction paper, was used. The base of the screen extended 6.5 cm from the back face, providing not only stability, but also a small ledge that the disks could rest upon. All objects were manipulated by an experimenter wearing ivory-colored gloves who placed the objects on and removed them from the stage described below.

4.1.4. Procedure

The procedure was the same as in Experiments 1 and 2 except for the following details. The experiment began with the raising of a black felt curtain to reveal the orange screen centered on the stage. Subjects sat on parents' laps at a distance of approximately 1.6 m from the middle of a three-sided white posterboard stage, 55 cm (tall) $\times$ 90 cm (wide) $\times$ 45 cm (deep), with a light blue floor, illuminated by two concealed 40-W lamps. At that distance, the red objects had an average luminosity of 4.56 cd m^2 and the green objects 3.39 cd m^2. The room was dimly lit and subjects, parents, and the stage were screened off from the rest of the room by dark drapes. The back wall of the stage was covered with a rectangular lattice of white posterboard that served to occlude the sides of a 'trapdoor' at the bottom center of that wall.

Each object was stationary and visible for around 3.5 s during each presentation, giving a total of 7 s per familiarization trial.

As before, immediately following the familiarization trials, three identical test trials were given. In each test trial, the two disks used during familiarization trials were pulled out sequentially for a single presentation then returned behind the screen. The screen was then lifted offstage to reveal the outcomes shown in Fig. 5. The occluded trapdoor in the back of the stage was used to enable the experimenter to 'swap' objects. She introduced her left hand through the door and used this hand to pull an object off the ledge on the back side of the screen and then place an object back on the ledge on the back of the screen. After removing her left hand, she closed the door again, so that the back wall would appear completely uniform when the screen was later removed. The left–right positions of the disks were counterbalanced across presentations. In the Control and Identification-by-Color conditions, the color of the disk last visible immediately prior to removal of the screen was counterbalanced across subjects.

4.2. Results

Inter-observer agreement calculated as in Experiment 1 was 94.5%. There were no statistical effects of gender, color of object first moved, left–right position of changed object, or color of changed object. Mean looking times of infants in the Control, Individuation-by-Color, Identification-by-Color, and Identification-and-Individuation-by-Color conditions were 9.5, 15.9, 12.4, and 18.2 s, respectively (Fig. 6). We analyzed these results using a repeated measures ANOVA with factors Trials (3) $\times$ Color-on-Individuation (2) $\times$ Color-on-Identification (2). The levels of factor Color-on-Individuation were Groups 1 + 3 (no number change) and Groups 2 + 4 (number change). The levels of factor Color-on-Identification were Groups 1 + 2 (no identity change) and Groups 3 + 4 (identity change). This analysis showed significant main effects of Trials [$F(2,88) = 11.21$, $P < .001$] and of Color-on-Individuation [$F(1,44) = 9.04$, $P = .004$]. The effect of Color-on-Identification was not significant [$F(1,44) = 2.95$, $P = .09$] and there were no interactions ($F < 1$).

To compare the size of the two effects that color had — on individuation and on identification — we calculated the amount of variance accounted for, using η^2. Color-on-Individuation factor accounted for 17% of the variance, while Color-on-Identification accounted for 6.3%.

4.3. Discussion

Taken together with the results of Experiment 2, the results of the present experiment show that, under these testing conditions, color difference has little or no effect on identification. The very same color difference, however, produces a large effect on individuation. The comparison of main effects in the present experiment is based on 24 subjects per group, a sample size that is fairly large by the standards of the infancy literature. Our negative result on identification is therefore unlikely to be a Type II error by conventional standards. However, the more informative result is the effect size comparison showing that color had a nearly three times larger effect on individuation than on identification. This is striking because both effects reflect exactly the same experimental manipulation, namely, the colors of the objects shown during familiarization. Color difference

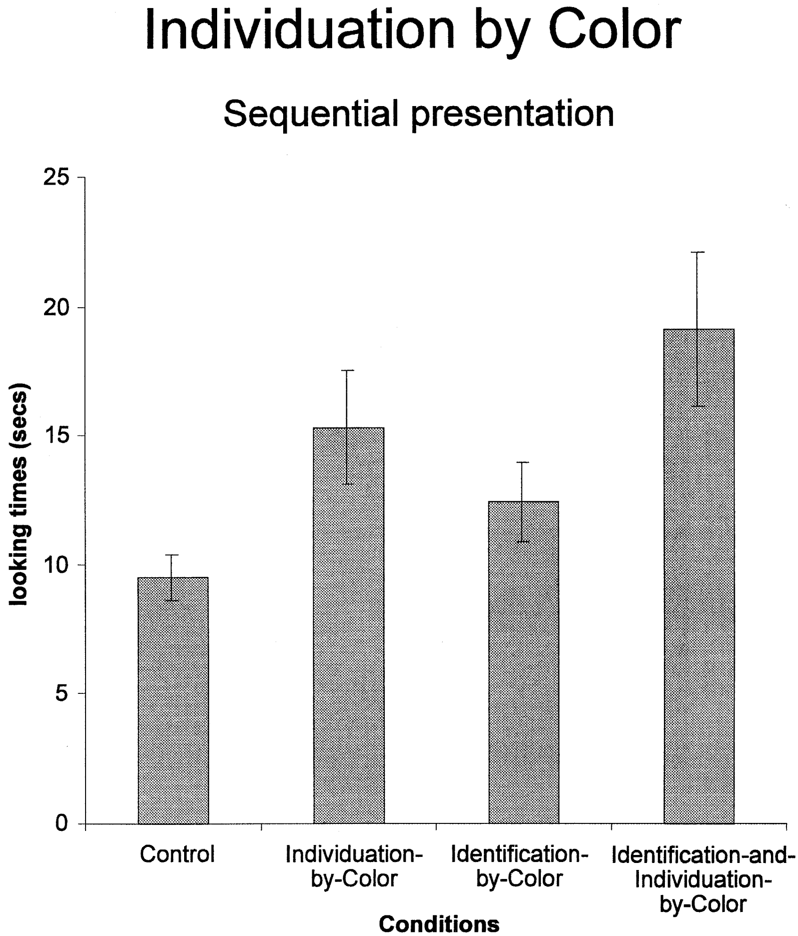


Fig. 6. Results from Experiment 3.

had a potent effect upon number expectations even as it had little effect on identity expectations.

It is possible that sequential presentation of the color difference placed a burden on infant processing that adversely affected the binding of color information to the OR (relative to shape information). Xu and Carey (1996) 'helped' their younger infants to individuate by using simultaneous presentation. Perhaps, simultaneous presentation will help our infants with identification, e.g., by increasing the salience of the side-by-side color difference. In our next experiment, therefore, we attempted to simplify the infant's task by presenting the objects together, so that their color difference would be obvious and detectable without memory.

5. Experiment 4

5.1. Method

5.1.1. Design

There were two conditions. In the Control condition, infants were familiarized with two identical red (or green) disks shown simultaneously. In the Identification-by-Color condition, subjects were familiarized with a red disk and a green disk shown simultaneously. In both conditions, following familiarization, the screen was removed to reveal two red (or two green) disks. For control subjects, colors of objects matched across familiarization and test (see Fig. 7).

5.1.2. Subjects

Twenty-four full-term infants (14 females and 10 males between 11 months and 12 days and 12 months and 21 days, mean = 12 months and 7 days) were randomly assigned to one of two conditions, Control or Identification-by-Color, with 12 infants per group. Ten further subjects were excluded because of sleepiness/distress.

5.1.3. Materials

Materials were the same as Experiment 3.

5.1.4. Procedure

The procedure was the same as Experiment 3 except that the stimulus objects were presented simultaneously during familiarization as well as during test. On each familiarization trial, the experimenter pulled the first disk out from behind the screen and placed it next to the screen. Then she pulled out the second disk and placed it next to the first so that both were visible. Then the first object was returned behind the screen, followed by the second. This sequence was repeated, completing a familiarization trial. As before, timing of the presentation was controlled by matching movements to a metronome beating every second. Each movement lasted for 1 s. Each object was stationary and visible for around 6 s during each of the two presentations per familiarization trial. The objects overlapped for four of these seconds; therefore, assuming the infant split attention evenly during the overlap, each object on average was exposed for 4 s for each of two presentations per trial, giving a total of 8 s exposure per familiarization trial. We thus again increased (to 8 s) the amount of time given the infants to encode the color of an object per familiarization trial from 4 s in Experiment 2 and 7 s in Experiment 3.

As before, immediately following the familiarization trials, three identical test trials were given. In each test trial, the two disks used during familiarization trials were pulled out for a single presentation then returned behind the screen. The screen was then lifted offstage to reveal two identical red disks. The left–right positions of the disks were counterbalanced across presentations. In the Identi-

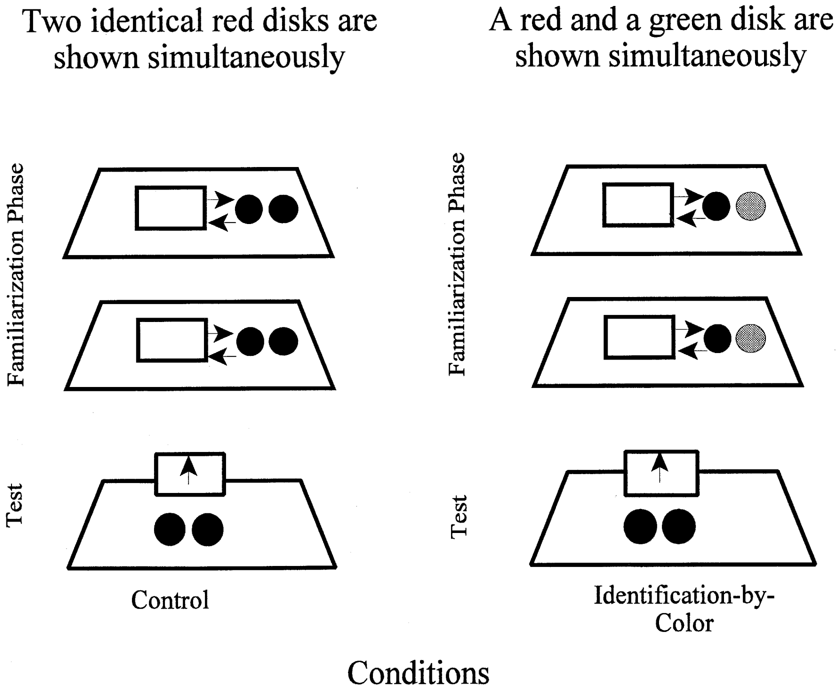


Fig. 7. Experiment 4 began with three familiarization trials in which two disks, either identically colored (both red or both green; Control condition) or differently colored (red and green; Identification-by-Color condition), were both removed from and returned behind a screen. The objects were moved individually but were simultaneously visible side by side for 4 s; each object was also visible alone for an additional 2 s during each presentation. Each familiarization trial consisted of two such presentations. In the test trials of both conditions, the objects were presented once more and then the screen was removed to reveal two identically colored disks. In the Control condition, the screen revealed the two familiarized disks. In the Identification-by-Color condition, the screen revealed one of the previously familiarized disks plus a new identically colored disk. In this condition, the color of object moved first and the color of changed object were counterbalanced across subjects.

fication-by-Color condition, the color of the disk last visible immediately prior to removal of the screen was also counterbalanced.

5.2. Results

Inter-observer agreement calculated as in previous experiments was 94.4%. The mean looking times of subjects in the Control and Identification-by-Color conditions were 9.0 and 9.4 s, respectively (Fig. 8). A repeated measures ANOVA with factors Trials (3) × Conditions (2) showed a significant effect of Trials [$F(2,44)=3.48$, $P=.04$], reflecting a uniform decline in looking times across trials. Conditions was not significant ($F<1.0$). Effect size η^2 for Conditions was very small (accounting for 0.4% of the variance). There were

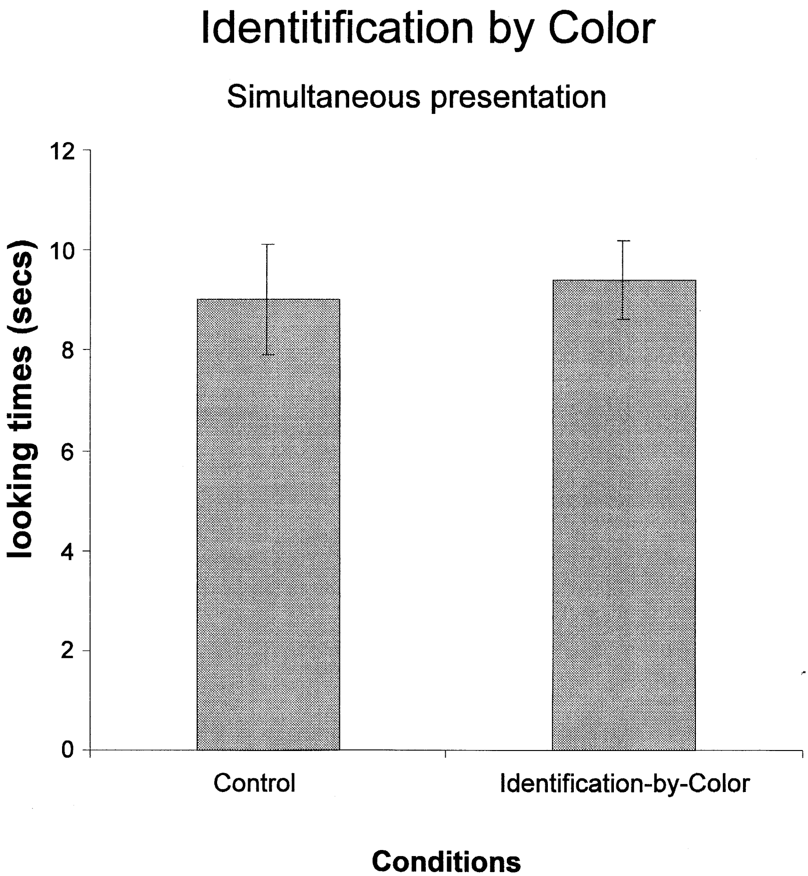


Fig. 8. Results from Experiment 4.

no statistical effects of gender, color of object moved first, or color of changed object.

5.3. Discussion

Despite our attempts to help infants identify by color with simultaneous presentation, we found virtually no effect of color on identification. With simultaneous presentation, the objects can be individuated by location. However, while they are side by side, there is opportunity for the infants to actively compare the objects (Mandler, 1992) and to note their color difference without having to rely on memory. Despite this, following familiarization to differently colored objects, infants were not surprised when the screen revealed two identically colored objects.

6. General discussion

At 12 months, infants apparently will use shape differences both to individuate and to identify objects through occlusion when the objects are presented sequentially. At the same age, color appears to be used only to individuate objects. Our infants did notice the color of the objects that we showed them. If shown two differently colored objects sequentially, they expected two objects to be revealed. If shown two same colored objects sequentially, infants did not expect two objects to be revealed. Despite this, infants had no clear expectation of *which* color each object should be. If color is not 'important' enough to the infant to determine identification, then why should it have been 'important' enough to determine individuation? After all, the individuation judgment must involve identifying successive object presentations as 'same' or 'different' based on color. So how are we to account for this apparent paradox?

The key will be to understand the underlying processing mechanisms. Depending upon the exact circumstances, tracking physical objects will involve different kinds of interactions between sensory systems, working memory representations, and long-term memory representations. Our current observations suggest that there are at least two distinct ways in which color information can function. One is to signal for the establishment of a new OR. A second is for color information to feed into and bind with the OR. What our results suggest is that the first process can sometimes occur without the second.

We do *not* claim that infants *never* can identify objects by color. Nor do we suggest that infant ORs are incapable of representing color. On the contrary, we believe it is perfectly possible for an infant OR to bind color information. What we do propose is that color information is not *necessarily* entered into an OR; it is possible for an OR to fail to specify the color of the object. Secondly, even in the case where an OR has been established on the basis of detecting a color difference between one object and another, the resulting OR does not *necessarily* contain color information. If true, these claims have important implications for the nature of infant ORs and for the processes that create and modify ORs.

6.1. A model for infant OR

We propose the following model. The infant OR can be extremely sparse and lack any featural information whatsoever. For example, the OR can be a 'bare' index or pointer of the sort discussed by Leslie et al. (1998). The 'bare' OR would simply allow attention to move rapidly to the current location of the object, but would not contain even shape information. This model is consistent with previous findings. The younger infants of Xu and Carey (1996) who succeed in their spatiotemporal condition may have indexed two objects without considering featural information. Likewise, the 5-month-olds studied by Simon et al. (1995) expected a certain number of objects without apparently expecting the objects to have determinate shapes. There may, however, be conditions under which even young babies will bind shape information (Wilcox, personal communication). Our results from Experiment 1 suggest that by 12 months, infants routinely bind shape information to the OR.

We turn now to consider how this model accounts for our color results. Wilcox (1999) reports that infants individuate by shape before they individuate by color. It may be that a similar pattern also applies to identification, but at older ages. That is, our 12-month-olds may be individuating by both shape and color, and identifying by shape but not yet by color. Below, we spell out this possibility in detail.

The first time our infants see a red disk emerging from behind the screen, its initial appearance triggers the establishment of a new OR. At the same time, activity in the visual system registers its color. The disk goes back behind the screen. When the green disk subsequently emerges, its color is detected as novel. A 'novelty signal' leads to the establishment of a new OR. Now the infant has two active ORs. When the red disk appears for a second time, its color is already registered and thus, there is no novelty signal to generate a third OR. When the screen is removed, the infant attempts to match objects to ORs. If a match is made, looking times will be shorter than if a match is not made. If color information has not been incorporated into the OR, then color will not be an issue in matching. Thus, if the infant has set up two ORs on the basis of seeing a red disk followed by a green disk, and then is shown two red disks when the screen is removed, he will be able to match both ORs because there are two objects. The fact that both objects are red will not matter because the infant is not searching for a *green* object or a *red* object. However, if the infant has been familiarized to identical red disks shown sequentially one at a time, then only a single OR will have been established. In this case, if the screen reveals two red disks, only one OR will find a match, while the second object will be unrepresented or 'unexpected,' leading to longer looking times.

In support of the above account, we found a clear effect of color on individuation (Experiment 3). However, across three experiments, we found no significant effects of color on identification. While estimates of its effect size ranged from 0.4% to 6.3% of the variance, we are inclined, on the whole, to dismiss the effect. However, we remain open to the possibility that color may have a small effect on identification and that its effect is additive with its effect on individuation. Our model can accommodate this possibility in one of (at least) three ways. The first possibility is that when a color feature triggers an OR, it is routinely bound to the OR; however, it then decays much more rapidly than the OR itself. This leaves the OR without color information.

The second possibility is that, despite rapid decay, the color feature was available long enough between object presentations to produce individuation, but not long enough between object occlusion and screen removal to allow identification of both objects. During familiarization, there was a period of about 1 s between presentations of the green and the red objects. Perhaps, infants remembered color for about 1 s, allowing them to note that the second object presented was different from the first. During test, however, the time between the occlusion of the *first* object and the removal of the screen was about 2 s in Experiment 4 and about 4 s in Experiments 2 and 3. Perhaps, this delay was too long for them to remember the color and therefore to notice the change. Two things argue against this possibility. First, infants would have to remember the color of the second object (occluded for 1 s) during test and have noticed when *its* color was changed. However, there was no effect of changing color of last vs. first hidden object. Second, to effectively individuate by color, infants would have remembered color between each *re*presentation of the same object — about 4 s — and not just between presentations of different objects.

The third possibility is that there is a nonzero probability that color information gets bound to the OR; however, this probability is substantially lower than the probability that a color signal will trigger an OR. Therefore, infants will often have an OR created by a novel color signal that does not contain information about color.

Why shape and color (and other kinds of information) should enter the OR differently is an interesting question for future research. Plausibly, shape information is more important than color for recognizing object kind and this may play a role in directing attention to shape.

6.2. Investigating identification and the OR

Leslie et al. (1998) have highlighted parallels in the literature on adult visual attention to the present distinction between individuation and identification. It remains to be seen how far such a distinction is relevant to the infant's object concept. The studies reported here are a first step. The issue can be explored further by extending individuation studies to include identification.

There are at least three possible patterns of relation between individuation and identification that future studies might reveal. First, a given type of property information may fail to influence the establishment of ORs because it lacks salience or is not attended. In this case, it would not be surprising if the information does not bind to the OR.

Another possibility is that a given type of property information may influence both individuation and identification. Many accounts make the commonsense assumption we discussed earlier that information that triggers an OR will automatically be included in the OR. This assumption may not be essential to some of these accounts (e.g., Wilcox, 1999). However, this assumption seems to be demanded by Xu and Carey's (1996) sortal theory of infant OR. The sortal theory states that a sortal concept provides criteria for individuation and identification. These have to be the same criteria because individuation judgments and identity judgments are not logically independent. Therefore, if the OR is a sortal representation, it seems there should be no dissociation between information used to individuate and information used to identify an object.

Finally, there is the third possibility that we have proposed here in which information may play distinct roles in individuation and identification. According to our proposal, individuation is easier than identification.

By studying the relationship between individuation and identification, we can address questions regarding the nature and variety of infant ORs as well as the processes that create and modify ORs.

Acknowledgments

We are grateful to Susan Carey, Fei Xu, Renee Baillargeon, Zenon Pylyshyn, Brian Scholl, Jerry Fodor, Bela Julesz, Elizabeth Spelke, and Ann Treisman for helpful discussions and to Jacob Feldman, Greg Rouen, Zsuzsa Kaldy, Patrick Cavanagh, and Eileen Kowler for discussion and comments on earlier drafts, and to two anonymous reviewers. This research was supported by NSF grant nos. SBR-9616342 and BCS-0079917 awarded to A.M.L.

References

Baillargeon, R. (1986). Representing the existence and the location of hidden objects: object permanence in 6- and 8-month-old infants. *Cognition*, *23*, 21–41.

Baillargeon, R. (1987). Young infants' reasoning about the physical and spatial properties of a hidden object. *Cognitive Development*, *2*, 179–200.

Baillargeon, R., Spelke, E. S., & Wasserman, S. (1985). Object permanence in five-month-old infants. *Cognition*, *20*, 191–208.

Bornstein, M. H., Kessen, W., & Weiskopf, S. (1976). The categories of hue in infancy. *Science*, *191*, 201–202.

Coldren, J. T., & Colombo, J. (1994). The nature and processes of preverbal learning: implications from nine-month-old infants' discrimination problem solving. *Monographs of the Society for Research in Child Development*, *59* (4), 1–74 (Serial No. 241).

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: object-specific integration of information. *Cognitive Psychology*, *24*, 175–219.

Kellman, P. J., & Spelke, E. S. (1983). Perception of partly occluded objects in infancy. *Cognitive Psychology*, *15*, 483–524.

Leslie, A. M., & Keeble, S. (1987). Do six-month-old infants perceive causality? *Cognition*, *25*, 265–288.

Leslie, A. M., Xu, F., Tremoulet, P., & Scholl, B. (1998). Indexing and the object concept: developing 'what' and 'where' systems. *Trends in Cognitive Sciences*, *2*, 10–18.

Mandler, J. M. (1992). How to build a baby, II: Conceptual Primitives. *Psychological Review*, *99*, 587–604.

Piaget, J. (1955). *The child's construction of reality*. London: Routledge & Kegan Paul.

Pylyshyn, Z. W. (1989). The role of location indexes in spatial perception: a sketch of the FINST spatial index model. *Cognition*, *32*, 65–97.

Pylyshyn, Z. W. (1994). Some primitive mechanisms of spatial attention. *Cognition*, *50*, 363–384.

Sagi, D., & Julesz, B. (1985). 'Where' and 'what' in vision. *Science*, *228*, 1217–1219.

Scholl, B. J., & Leslie, A. M. (1999). Explaining the infant's object concept: beyond the perception/cognition dichotomy. In: Lepore E., & Pylyshyn Z. (Eds.), *What is cognitive science?* (pp. 26–73). Oxford: Blackwell.

Scholl, B. J., & Pylyshyn, Z. W. (1999). Tracking multiple objects through occlusion: clues to visual objecthood. *Cognitive Psychology*, *38*, 259–290.

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

Spelke, E. S. (1988). The origins of physical knowledge. In: Weiskrantz L. (Ed.), *Thought without language* (pp. 168–184). Oxford: Clarendon Press/Oxford Univ. Press.

Spelke, E. S. (1994). Initial knowledge: six suggestions. *Cognition, 50*, 431–445. In: J. Mehler, S. Franck (Eds.), *Cognition on cognition* (pp. 433–447). Cambridge, MA: MIT Press (1995) (reprint).

Spelke, E. S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review*, *99*, 605–632.

Spelke, E. S., Kestenbaum, R., Simons, D. J., & Wein, D. (1995). Spatiotemporal continuity, smoothness of motion and object identity in infancy. *British Journal of Developmental Psychology*, *13*, 113–142.

Treisman, A. (1988). Features and objects. The fourteenth Bartlett Memorial Lecture. *Quarterly Journal of Experimental Psychology*, *40*, 201–237.

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

Wilcox, T., & Baillargeon, R. (1998). Object individuation in infancy: the use of featural information in reasoning about occlusion events. *Cognitive Psychology*, *37*, 97–155.

Wynn, K. (1992). Addition and subtraction by human infants. *Nature*, *358*, 749–750.

Xu, F., & Carey, S. (1996). Infants' metaphysics: the case of numerical identity. *Cognitive Psychology*, *30*, 111–153.