RuCCS TR-41
April, 1998

Individuation and Identification of Physical Objects: Evidence From Human Infants

Patrice D.Tremoulet
Center for Cognitive Science(RuCCS)
Rutgers University
pollyt@ruccs.rutgers.edu

Technical Report #41
Center for Cognitive Science (RuCCS)
Rutgers University, Busch Campus
Psychology Building Addition
New Brunswick, NJ 08903

INDIVIDUATION AND IDENTIFICATION OF PHYSICAL OBJECTS: EVIDENCE FROM HUMAN INFANTS

by

PATRICE D. TREMOULET

A thesis submitted to the

Graduate School-New Brunswick

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree of

Master of Science

Graduate Program in Psychology

written under the direction of

Alan M. Leslie

ABSTRACT OF THE THESIS

Individuation and Identification of Physical Objects:

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by PATRICE D. TREMOULET

Thesis Director:

Alan M. Leslie

The research presented here investigates how infants use perceptual features, specifically shape and color, to individuate and identify physical objects. Individuation is the process whereby objects come to be represented as distinct individuals. This process enables infants to establish the notions *single object* and *more than one object*. Object identification is the process whereby a unique identity is associated with an object, giving rise to the notion *the same one*. Experiment **1** reveals that 12-month-olds will individuate physical objects based upon color differences, but will not identify objects by color. This seemingly paradoxical result is explained in terms of a new theory of the infant's object concept, inspired by theories of object-based mechanisms of selective attention. Experiment **2** demonstrates that 9-month-old infants who have individuated objects based upon spatiotemporal properties do not always identify these objects by their shapes. There may be a developmental progression in the use of features to individuate and identify physical objects. Future work (some already in progress) will explore this possibility.

Acknowledgement

I would like to acknowledge the assistance of the many undergraduate research assistants who worked in the Cognitive Development Laboratory during the academic years 1995-1996 and 1996-1997. In addition, I am grateful to Kathleen VanderGoot for her help in collecting data and managing the undergraduate research assistants. Last, but certainly not least, I would like to thank Alan Leslie for his advice and support.

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Introduction

It was once thought that human infants were incapable of representing physical objects as concrete, three-dimensional volumes existing independently of sensory contact (Piaget, 1955). However, recent experimental work capitalizing upon infants' propensity to look longer at unfamiliar events has undermined this view. Empirical studies have used visual habituation, preferential looking, violation of expectation, and other looking-time-based paradigms to show that infants less than six months old appreciate that objects are substantial, relatively permanent, and occupy space (Baillargeon, Spelke, & Wasserman, 1985), and to demonstrate that infants represent several abstract properties of physical objects. For example, we now know that young infants expect physical objects to follow continuous, non-intersecting paths in space and time (Spelke, 1988, 1994), and that they are sensitive to the numerosity of small sets of occluded objects (Wynn, 1992; Baillargeon, Miller, & Constantino, 1994; Uller, Carey, Huntley-Fenner, & Klatt, 1994). In addition, infants can attend to spatial and mechanical relationships among objects; they seem to understand that one object can launch another after a collision (Leslie & Keeble, 1987), that objects do not pass through one another (Baillargeon, 1987; Spelke, Breinlinger, Macomber & Jacobson, 1992), and that only a subset of physical objects exhibits certain special properties, such as self-initiated movement (Leslie, 1984a).

Despite growing evidence that infants possess a relatively sophisticated notion of physical objects, empirical work has also suggested that infants do not always use object properties the way adults do. For example, an adult who watches a sequence in which a distinctive object, such as a bright yellow rubber duck, is taken out from and placed back behind an occluding screen, and then a differently-featured item, such as a white foam ball, is taken out from and replaced behind the same screen, will typically conclude that there are two distinct objects behind the screen, and furthermore, that one of the objects is a white foam ball and the other object is a yellow toy duck. Under the same circumstances, however, 10-month-old infants do not appear to set up representations of numerically distinct individuals. (Xu & Carey, 1996).

In short, adults, but not 10-month-olds, will use featural differences both to individuate and to identify physical objects. Individuation is the process whereby objects come to be represented as distinct individuals. This process enables infants to establish the notions *single object* and *more than one object*. Object individuation is also inherently intertwined with object identification, the process which gives rise to the notion *same one*. In fact, object individuation and object identification presuppose one an other. However, for the purposes of this discussion they will be distinguished as follows: **Individuation** will be used to refer to the establishment of distinct object representations, and **Identification** will be used to describe the process of determining whether a new perceptual episode involves the reappearance of a previously seen object.

Individuation and identification can both take place either by *location* or by *feature*. That is, since there are constraints upon the manner in which an object's location and features can change over time, both differences in location and differences in features can be used to infer distinct individuals. In particular, an object can not instantaneously change location – it must follow a smooth path over space and time, and a single object can not be simultaneously centered at two distinct positions in space. Furthermore, gross featural changes do not typically occur in short time intervals, so gross featural differences should (typically) be interpreted as signifying different individuals. Thus, establishing representations of physical objects may involve any of the following four processes: individuation by location, individuation by feature, identification by location, and identification by feature.

The distinctions among these four processes are motivated by *object indexing* theory, a new theoretical framework which may be used to explain infants' (and adults') individuation and identification of physical objects. This framework is inspired by some current theories of adult attention, and has been very heavily influenced by two of them. The central concepts of these two theories, FINSTS and object files, will be briefly described below, followed by a quick overview of some the major ideas of the object indexing framework.

Pylyshyn (1989, 1994) argues that, in order to detect simple geometrical relations among the elements of a visual scene (e.g. being inside, or being collinear), the visual system must be able to simultaneously reference multiple objects. His model of such indexing is based on the notion of a "*FINST*" (*F*inger of *Inst*antiation). FINSTs are spatial indexes, assigned to items in the visual field. They can be assigned regardless of spatial contiguity, and serve as a means through which higher-level processes, such as focal attention, are able to access the items in the visual field to which the FINSTs are assigned. Like pointers in a computer data structure, they provide access to an information-rich location without representing that information themselves. Unlike pointers, however, FINSTs are limited in number; there are only about four of them. Finally, FINSTs are *sticky*: if an indexed item in the visual field moves, the FINST moves with it. Experiments using a multiple-object tracking paradigm offer support for the FINST-based theory of visual attention. Subjects in these experiments are able to track about four randomly moving targets among numerous identical moving distractors. Subjects are therefore attending to and tracking items and not regions of space (Pylyshyn et al., 1994).

Kahneman & Treisman (1984; Kahneman, Treisman & Gibbs, 1992; Treisman, 1988) propose a model of attention whereby an *object file* is opened whenever a object or an event is first detected. According to this model, a newly created object file contains only spatiotemporal information; only a location and a time are recorded initially. Like a FINST, an object file can function as an index to an object's location. However, unlike FINSTs which do not themselves contain any featural information, object files do generally contain featural information; this information is gradually added as it becomes available. The featural information contained in an object file can be added and changed without affecting its indexing function. Since making modifications to the contents of object files (spatiotemporal or featural information) is assumed to require attention, there is a limit upon the number of object files which can simultaneously be "open" for modification.

The Object Indexing Framework

A key postulate of object indexing is that attention can span a small number of physical objects by assigning to each a mental token, called an object index, that points at their actual or probable locations. Indexes are assigned primarily by location; however, they are not assigned to the locations themselves but to "bounded physical objects" (Spelke, 1988) in these locations. In addition, indexes can be assigned by feature if location information is ambiguous. Since, like FINSTs, object indexes are limited in number, they must be re-used; but assigned indexes must be de-assigned before they can be used again. There are three basic rules of index assignment:

1) a distinct object is assigned a single index;

2) once an index is assigned, it sticks to the object as the object moves through different locations in space;

3) if objects occupy distinct locations in space, different indexes may be assigned to each of them.

Leslie, Xu, Tremoulet & Scholl (in preparation) describe object indexing in full detail.

Object indexes cannot simply be identified with either FINSTs or object files. As originally defined, FINSTs are inherently tied to vision, whereas object indexes must operate cross-modally, e.g., to track objects in tactile or motor space. Furthermore, object indexes must track objects that are partially or completely occluded. In such cases the indexed item will not appear on the retina, and the locational access the index provides may be only approximate. While it is possible that FINSTs may operate under occlusion, FINSTs and object indexes may operate under different time scales. (After occlusion, it is likely that FINSTs will decay rapidly, but object indexes must endure for relatively long periods of time.) Object files also would be expected to behave differently under non-brief periods of occlusion than object indexes, since the former individuate perceptual *episodes* while the latter individuate physical objects. The re-appearance of a physical object from behind a screen could be considered a new perceptual episode but it is certainly not a new physical object. When an indexed object is temporarily occluded an then re-appears, it pulls the index with it. Meanwhile, the reappearance of a physical object should generate a new object file. As featural information becomes available, the new object file will be associated with, or collapsed into, the first.[1]

[1]It is unclear what happens in situations where the occlusion is very brief. Since opening a new object file requires attention, in cases of short occlusion it is likely that an existing object file would be updated instead of creating a new one, unless there is reason to open an additional object file anyway (e.g. the detection of a new object).

Finally, both the opening of an object file and the assignment of a new FINST can never be driven purely by featural information. In contrast, the object indexing framework allows for the possibility that, in situations where locational information is ambiguous, featural information is sufficient to drive the assignment of indexes. Despite these differences, object indexing framework inherits a very important property of FINST-based and object file-based theories: it contains a level of representation in which objects can be individuated independently of being identified. Object indexing theory assumes that *object individuation* is driven by an attentional mechanism which assigns indexes to distinct physical objects. It assumes that *object identification* is governed by whether an object has already been indexed or requires the initial assignment of an index. According to object indexing theory, featural information is attached to object indexes by a non-default process of feature binding.

The primacy of location information for assigning indexes under the object indexing framework suggests the following hypothesis: early in development, object indexation, and thus individuation, may be driven entirely by spatiotemporal information. For young infants, features may be bound to objects but only *after* the assignment of an index by location. Later in development, differences in features may be sufficient to motivate the assignment of a new object index. This hypothesis may be investigated empirically.

In short, although object indexing theory proposes a framework which may be used to account for infants' individuation and identification of perceptual objects, it leaves many questions open for empirical investigation: Is there a developmental progression from individuation by location to individuation by feature as hypothesized above? What is the role of *feature* in the case where objects are individuated by *location*? Are features bound to object representations when the individuals have been set up by location? These questions will be addressed by the experiments presented here. Before these experiments are introduced, however, some recent findings relevant to object individuation and object identification will be briefly reviewed.

Background & Methodology

Recent work bearing upon Object Individuation and Object Identification

There is a great deal of empirical evidence suggesting that even young infants individuate and identify by location, using spatiotemporal properties of physical objects. For example, Spelke, Kestenbaum, Simons, & Wein (1995) familiarized 4-month-old infants to a display in which an object moved behind an occluder, crossed a gap, and then moved behind a second occluder. They found that these infants then looked longer at a test display of two objects than at a test display of a single object, implying that the infants inferred that only one object was present during the habituation trials. Spelke et al. familiarized a second group of infants to a similar display in which an object moved behind one occluder and then a second identical object appeared from behind the far side of a second occluder without crossing the gap. This group of infants looked longer at the test display showing a single object than at the display showing two objects, implying that the infants inferred that there were two objects present during the habituation trials. These results indicate that infants use continuity of trajectory to determine object individuation.

Xu & Carey (1996) expanded upon Spelke et al.'s work. In the Xu & Carey paradigm, objects were removed from behind a single screen, placed in view of the infant, and then replaced behind the screen.[2] Initially, there were two objects behind the screen which belonged to different kinds and thus differed in many features. These objects were pulled out from behind the screen and displayed, either one at a time (properties condition) or both at the same time (spatiotemporal condition). Following familiarization, the screen

[2]The scenario described earlier with a duck and a ball emerging from behind a screen is an example of the Xu & Carey paradigm.

was removed to reveal either one of the previously shown objects, or both objects. Unfortunately, Xu & Carey's test displays suffered from a *baseline* problem: infants are predisposed to look longer at displays of two objects (especially two differently-featured objects) than at displays of a single object. To get around this problem, Xu & Carey measured their subjects' preference for two-object-displays in a series of pre-test "baseline trials." In the baseline trials, infants were presented with single-object- and two-object-displays, similar to the outcome displays of test trials, and their looking times were measured.

Xu & Carey found that the infants in their spatiotemporal condition looked the same amount of time at single-object-outcomes and as they did at two-object-outcomes; however, this pattern was significantly different from the pattern of looking times during the baseline trials. Thus, Xu & Carey interpreted their results as evidence that infants in their spatiotemporal condition expected there to be two objects behind the screen and were surprised to see outcomes with a single object. In contrast, in their properties condition (where the two different objects were never shown simultaneously), only older infants (around 12 months) looked as long at the unexpected single-object-outcomes as at the expected two-object-outcomes; younger babies (around 10 months) looked significantly longer at two-object-outcomes than at single-object-outcomes. (That is, the younger babies in the properties condition did not look differently in the test trials than they did in the baseline trials.)

Xu & Carey argue that younger infants do not know that, e.g., a cup and a ball, shown sequentially, must be two distinct objects; they suggest that the younger infants may expect only one object, or may be agnostic about the number of objects which must be behind the screen. However, it is possible that infants younger than 12 months old can use features to individuate objects; it may simply be harder for younger infants to overcome their baseline preference for two-object-displays than for older infants. It is also possible that the infants in Xu & Carey's properties/kind condition looked longer at the two-object-displays than the infants in their spatiotemporal condition did because those in the former condition were never exposed to a two-object-display (since, by design, they never saw two objects simultaneously) during the test trials, in contrast to those in the latter condition. This is also true of the infants who participated in habituation-based replications of their experiment.

Xu & Carey argue that their findings support Bower's (1974) theory of infants' earliest representations of object identity. Bower proposes that object identity is initially determined by spatiotemporal information alone. He claims that 3- to 4-month-old infants do not take features into account when establishing object identities, asserting that these young infants define the identity of moving objects in terms of their movements, and define the identity of stationary objects solely in terms of location. (Bower, 1974).

Although Xu & Carey's results are consistent with the hypothesis that young infants use spatiotemporal information before they use features to *individuate* objects, unfortunately, their technique can not address how infants *identify* objects, since it confounds identification with individuation. Xu & Carey tested whether infants expected two objects, but not on whether they expected the objects to have *particular* properties.

The only research described in print which bears upon infants' ability to *identify* objects is the work of Simon, Hespos & Rochat (1995). However, this issue was not the main focus of their work; they were investigating infants' understanding of arithmetic. Simon et al. first familiarized 5-month-old infants to two types of dolls (an "Ernie" and an "Elmo"). Then Simon et al. presented the infants with an addition event, run as follows: First, a doll was placed upon a stage and a small screen was positioned such that it occluded the doll. Next, a second doll was introduced onto the side of the stage and then placed behind the occluding screen. Finally, the screen was removed to reveal one of several outcomes. In the expected outcome, there were two dolls behind the screen corresponding (in identity) to the two dolls placed behind the screen in the addition event. In another two-object outcome, (impossible-identity correct-arithmetic), one of the two dolls had been surreptitiously replaced by a different doll (e.g. an Ernie was substituted for an Elmo). Much to their surprise, Simon et al. found that infants did not look longer at the "impossible-identity correct-arithmetic" outcome than they did at the expected outcome. In short, 5-month-olds seemed to understand that one object plus another object should yield two objects, but they did not appear to expect *specific* objects. Thus, the subjects in Simon et al.'s study did not use perceptual features to *identify* the dolls.

Unfortunately, the Simon et al.'s work suffers some methodological difficulties. For example, the two "different" object types used in their experiments were actually quite similar to one another; both were plastic dolls roughly the same size and shape. Moreover, these dolls were relatively complex objects. Simon et al. showed that, in principle, 5-month-old infants could discriminate these two objects, since a separate group of infants recovered interest to one doll after being habituated to the other. However, the similarity between the objects and the age of the subjects leaves open the possibility that with simpler, more contrastive objects and/or older subjects, identification by feature might occur.

In another study, focusing directly upon infants' identification of objects by feature Hall & Leslie (1995) improved upon the methods used by Xu & Carey and by Simon, Hespos & Rochat. Following Xu & Carey, Hall & Leslie familiarized 12-month-old infants with two different objects that were pulled out from behind and replaced back behind a screen, one at a time. However, the objects used by Hall & Leslie were very simple and differed only in a single feature, either shape or color. In addition, Hall & Leslie always tested infants with displays of two objects, thus avoiding Xu & Carey's baseline problem.

Hall & Leslie's test trials began like their familiarization trials, with two different objects pulled out from and then replaced behind the screen. Next, however, the screen was removed to reveal two objects. Half the infants saw the familiarized pair of objects (Expected Shape and Expected Color conditions). The rest of the infants were shown two objects which were identical to one of the familiarized objects (Drop Shape and Drop Color conditions). Hall and Leslie found that infants in their Drop Shape condition looked longer than infants in the Expected Shape condition. These infants apparently expected the screen to reveal two differently shaped objects, and looked longer when both objects had the same shape. In contrast, they found that infants in the Drop Color condition did not look reliably longer than infants in the Expected Color condition.

The methodology pioneered by Hall & Leslie (1995) will be adopted here to explore the mechanisms which may underlie object individuation and object identification. A first experiment builds upon the work described above which demonstrates that 12-month-olds can individuate and identify objects by feature, in particular by shape (Xu & Carey, 1996; Hall & Leslie, 1995). It explores the possibility that 12-month-old infants individuate objects by color without identifying objects by color. The second experiment examines Xu & Carey's finding that 10-month-olds do not individuate by feature but only individuate by location (Xu & Carey, 1996). Having individuated two objects by location, will 9-month-old infants then identify these objects by feature?

Experiment 1

Experiment 1 investigates whether 12-month-old infants use differences in color to individuate and identify physical objects. This experiment attempts to replicate Hall & Leslie's (1995) two color conditions (*Expected Color* and *Drop Color*), and extends their work by including two novel conditions. As noted above, Hall & Leslie found that infants who were shown two differently colored circles successively withdrawn from and replaced behind a screen looked about the same amount of time at an outcome where two identical circles were revealed as they did at the expected outcome, where two differently colored circles were revealed. This result is consistent with two possibilities; 12-month-olds may fail to individuate and to identify based upon color differences, or they may individuate based upon color, but not identify objects based upon color. Two new conditions are introduced: *Add Color & Object* and *Add Object Only*. These conditions are designed to distinguish between individuation by color and identification by color. In both these conditions, two identical objects are shown (one at a time) during familiarization trials, so that infants can not individuate based upon featural differences; hence, both spatiotemporal and featural information are consistent with there being only one object behind the screen. (Although logically there could be any number of objects behind the screen, it is plausible that infants, like adults, will conservatively assume the minimum number that they have evidence for.) If infants look longer at the same two-object displays under these conditions than they do in the first two conditions, then infants must expect two objects in the Expected Color and Drop Color conditions.

The second possibility described above, that infants can individuate based upon color differences but not identify based upon color, requires some comment; in order to individuate based upon color, one must attend to the colors of objects, and also remember the colors of objects which are not currently in view. However, the fact that infants might use features to set up distinct object representations does not entail that the representations which are created will record what those features are. For example, I could attend to a group of eight objects just long enough to count them, and disregard their features after determining that there were eight. Later, I would definitely expect there to be eight objects, but I might make mistakes about what sorts of features they possess. Similarly, the infant could attend to an object long enough to set up a representation for it, then notice that a second object differs somehow from the first, and set up a second object representation, but later be uncertain about precisely how the two objects differ. The object indexing theory introduced previously can account for this possibility: infants may assign object indexes based upon featural differences but fail to bind the featural information to these indexes.

Method

Subjects

Forty-eight full-term infants participated in the study (26 female and 22 male), age range from 11;16 to 13;1 (mean age 12;7). Equal numbers of infants were tested in each of the four conditions (mean ages 12;8, 12;10, 12;4, and 12;4). 16 additional infants were tested and excluded from the sample due to fussiness (10), experimenter error (2), observer error (2), or parental interference - pointing to stage or talking (2). All infants were recruited by obtaining copies of birth announcements from local newspapers and contacting their parents by mail.

Materials

Two pairs of identical wooden circles, the first pair painted bright red, and the second pair painted bright green were used in all trials. The circles were 10.5 cm in diameter, and .9 cm thick. A small wooden cube (2 cm^3) was glued to the back (the non-painted side) of each circle for stability, so the circles could stand on their "edges". In addition, a white posterboard screen 34 cm x 33 cm, with the front face covered by orange construction paper, was used as an occluder in all trials.

Apparatus

The occlusion events were presented on a three-sided white posterboard mini-stage, 55 cm (tall) by 90 cm (wide) by 45 cm (deep), with a light blue floor. The side walls of the stage were plain white, and the back wall was textured white, decorated with 3 cm wide strips of white poster-card arranged in a lattice pattern. This decoration disguised a 25 cm by 25 cm door centered in the back wall of the stage, through which objects were put in or taken out as necessary.

Caregivers were seated, with infants in their laps, in a generic plastic chair, whose back was 160 cm from the front of the stage. Two black curtains extended from either side of the stage back behind this chair, concealing the rest of the room from the subjects (and caregivers) when they were seated before the stage. A surveillance camera was mounted just above the top of the stage, hidden behind a black window shade, which had a small hole cut out of it to allow the camera lens to focus upon the subjects. A second surveillance camera was mounted upon one of the curtain holders, capturing the events shown to the subjects on stage.

The outputs from the two cameras, plus that from a small backstage microphone, were piped into a video mixer, and then sent to a VCR and to a black and white television monitor. An observer sat facing the monitor, and recorded when the babies were looking at the stage, using two push-buttons which were connected to a 486 computer. The top half of the monitor's image, which showed the events occurring on the stage, was blocked from the observers view with an opaque white cloth taped to the top of the monitor. Thus, the observer was always blind to the condition the subjects were in.

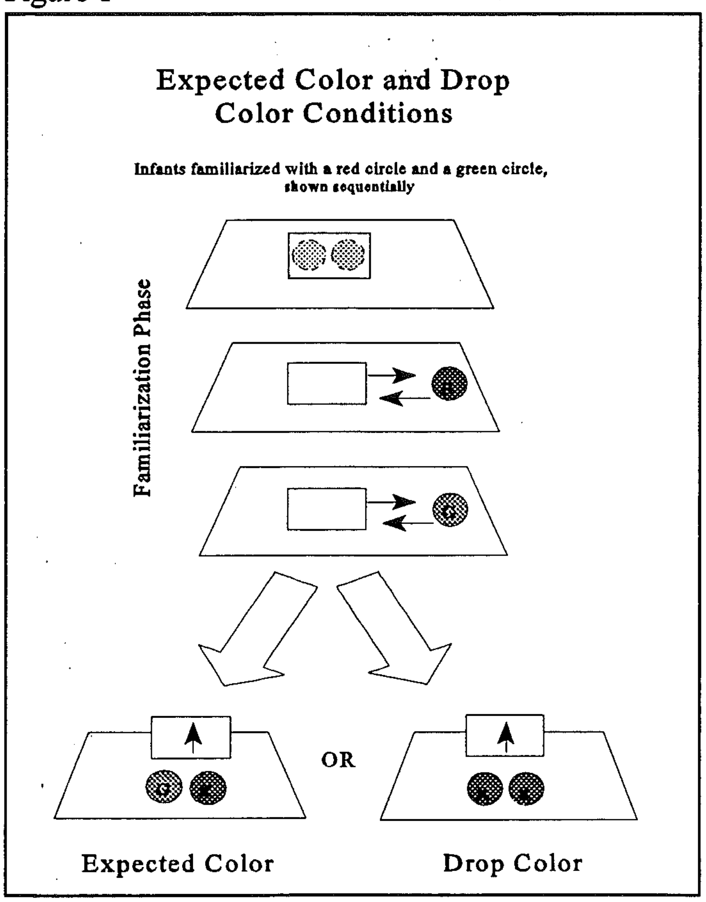
The stage was lit from above and from one side of the baby; otherwise the room was dark. The caregivers were asked to sit quietly during the experiment, and not to attempt to draw the baby's attention either towards or away from the stage. They were forewarned that they would be prompted to close their eyes before the test trials began, and were instructed to keep their eyes closed until the experimenter had completed the session, so they would not influence the baby's response.

Design and Procedure

Fourty-eight infants were randomly assigned to each of the four conditions (twelve per condition): Drop Color, Color Control, Add Color & Object and Add Object Only. (See Fig. 1 for schematic representations of Drop Color and Color Control, and Fig. 2 for schematic representations of Add Color & Object and Add Object Only.)

Introductory phase: After seating the baby and the caregiver, and pulling back the curtians to occlude the rest of the room, the experimenter prompted the observer to turn on the stage lights using one of the push-buttons. All experiments began with the screen centered upon the stage, and two objects hidden behind the screen. The experimenter lowered her hand onto the stage from above, to one side of the screen. (Only the experimenter's hand was visible to the infant, and the experimenter was wearing a pair of off-white elbow-length gloves, with small bells attached to the wrist of the right glove.) Then the experimenter tapped lightly on the stage twice, and called out to the baby "Hi (baby name)." Next, she moved her hand across the front of the stage, and tapped twice on the opposite side of the stage, calling "Can you look here for me?" Finally, she raised her hand to the top center area of the stage, just below the camera, and called out "And look here (baby name)," twisting her hand so that the bells would ring. After withdrawing her hand, she said to the infant. "Good job. OK, let's see what I have for you today," and immediately began the familiarization trials. The introductory phase served two purposes; first, it served to familiarize the infant with the experimenter's gloved hand and the ringing bells; second, it provided a quick calibration check for the observers when the baby was prompted to look towards various parts of the stage.

Figure 1



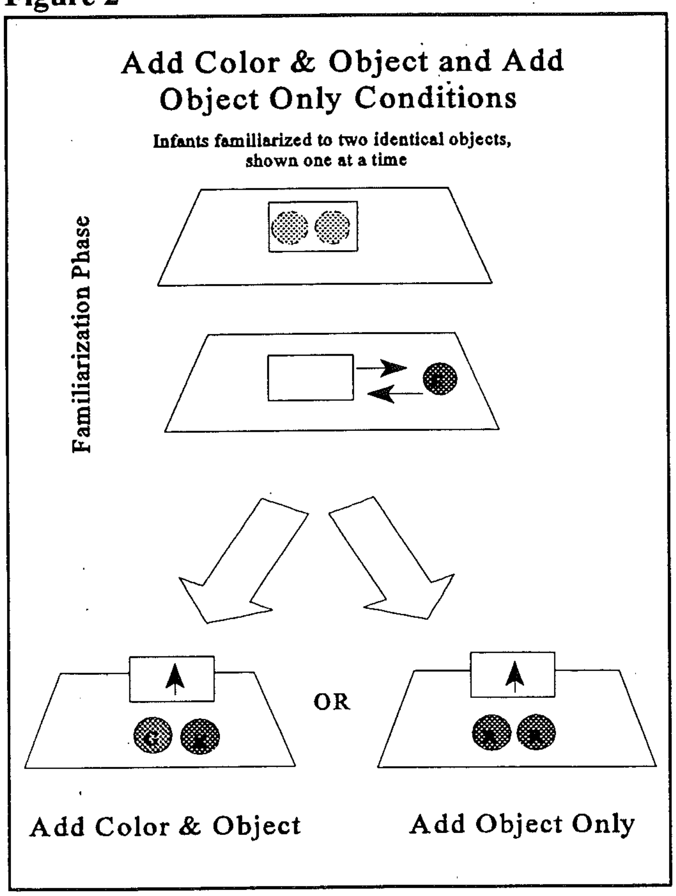
Familiarization trials: Expected Color and Drop Color conditions: The familiarization trials give the baby an opportunity to look at each of the objects (a red circle and a green circle) which would be used during the test trials. Three identical familiarization trials were presented. The experimenter lowered her hand onto the stage behind the screen, and pulled out an object from behind the screen, placing it on the side of the stage, next to the screen. After approximately one second, the experimenter put the object back behind the screen. (If the infant did not look at the object after it was pulled out from behind the screen, the observer would signal to the experimenter, who would tap her hand, ring the bells on her wrist, or call out the subject's name to make sure the subject saw the object.) After another second, the experimenter pulled the second object out from behind the screen, left it in view for a second, and replaced it behind the screen. Then the entire sequence was repeated. After the fourth in/out sequence, the stage lights were turned off for three seconds, then relit, and the next trial was started. At the end of the third familiarization trial, the experimenter said to the parent "OK, this is the part where I'm going to ask you to close your eyes."

Test trials: Expected Color condition: Five identical test trials followed the familiarization trials. Each test trial began like the familiarization trials, with the two objects sequentially pulled out from and then replaced behind the screen. Unlike the familiarization trials, however, each object was only pulled out and replaced once, and then the experimenter shook her hand to ring the bells, and grasped the top of the screen. As the experimenter began lifting the screen, she called out "Now" to signal to the observer to begin recording the baby's looking time. When the screen was removed, the two objects shown during the familiarization trials were revealed, sitting next to one another at the center of the stage. The trial ended when the baby had looked away for two consecutive seconds, calculated by the computer from the observer's button-presses. When the trial ended, the computer turned off the stage lights, and the experimenter removed the objects, then set up the stage for the next trial. The order of object presentation (red first or green first) and side of stage which objects were pulled out onto (left or right) were counterbalanced across subjects.

Test trials: Drop Color condition: The Drop color condition was identical to the Expected Color condition except that, when the screen was removed, two identical objects (e.g. two red circles) were presented to the subject, sitting next to one another at the center of the stage. This was achieved by using the hidden door in the back wall to exchange one of the objects for another during the test trials. The color of the first object presented (red or green), the side of stage which objects were pulled out onto (left or right), and the color which was "dropped" in the test display (red or green) were counterbalanced across subjects.

Familiarization trials: Add Color & Object and Add Object Only conditions: Once again, there were three identical familiarization trials. These trials were identical to those of the replicated conditions, except that two identical objects (e.g. two red circles) were pulled out from and then replaced behind the screen, one at a time.

Figure 2



Test trials: Add Color & Object condition: Five identical test trials were presented. Each began like a familiarization trial, with each of the two identical objects (e.g. red circles) pulled out from and then returned behind the screen once. Then, as in the two replicated conditions, the experimenter shook her hand to ring the bells, and grasped the top of the screen. As the experimenter began lifting the screen, she called out "Now" to signal to the observer to begin recording the baby's looking time. When the screen was removed, two differently-colored objects were revealed (a red circle and a green circle), sitting next to one another at the center of the stage. The trial ended when the baby had looked away for two consecutive seconds, calculated by the computer from the observer's button-presses. When the trial ended, the computer turned off the stage lights, and the experimenter removed the objects and set up the stage for the next trial. The color of the object presented during familiarization (red or green), the side of the stage which the objects were pulled out onto (left or right), and the side of the stage on which the familiarized object appeared in the test display after the screen was removed (left or right) were counterbalanced across subjects.

Test trials: Add Object Only condition: The Add Object Only condition was identical to Add Color & Object condition except that, when the screen was removed, the two identical objects shown during the familiarization trials, (e.g. two red circles) were presented to the subject, sitting next to one another at the center of the stage. The color of the familiarized object (red or green) and the side of stage which the object was pulled out onto during familiarization (left or right) were counter-balanced across subjects.

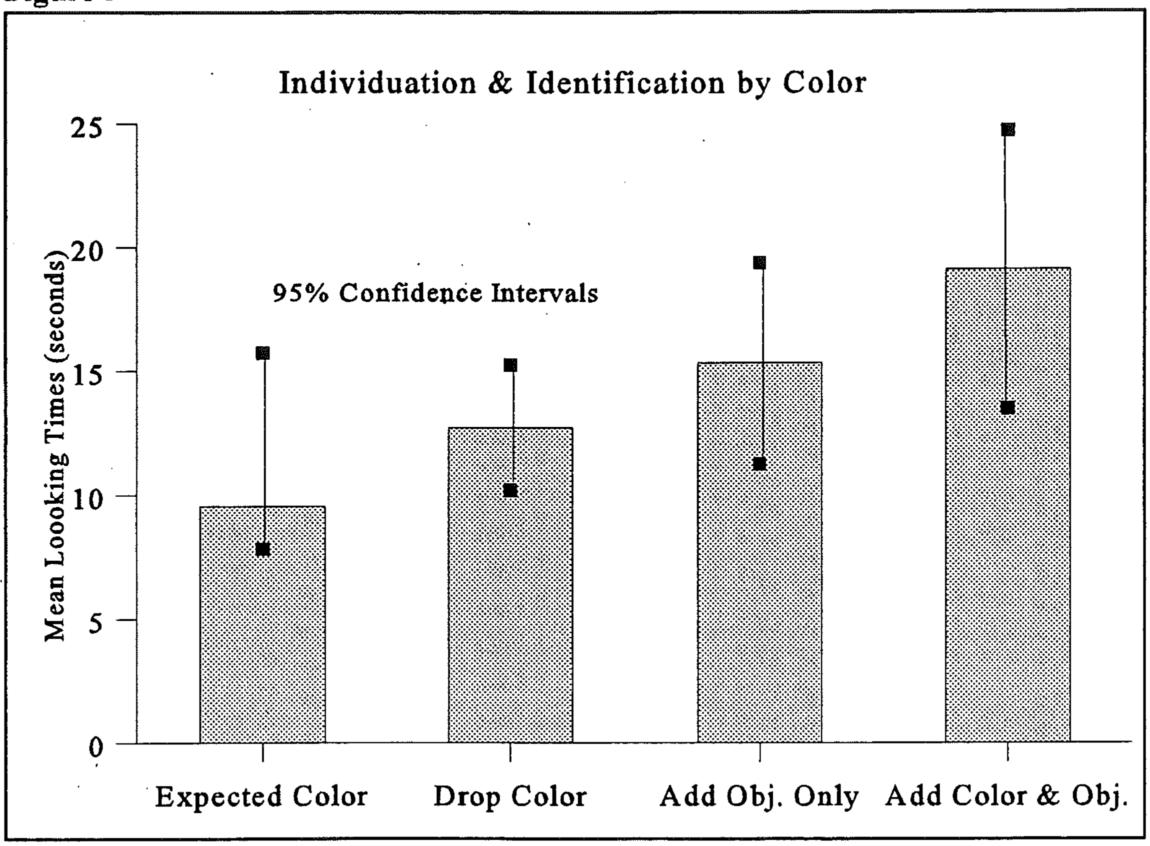
All of the 48 subjects were re-scored by a second observer, using the videotape made during the experimental session. Like the original observers, the second observers were blind to the condition because the top half of the monitor was occluded during the re-score sessions. For each trial, a percentage disagreement (the difference in times recorded by the primary and second observers divided by the time recorded by the primary observer) was calculated. These percentage disagreements were averaged over the trials and then subtracted from 100% to yield reliability scores. Inter-scorer reliability averaged 94.4%.

Results

The mean looking time over the first three test trials was computed for each subject. Figure 3 presents the means of these mean looking times for each condition. (We chose to analyze the data with three trials since analysis showed large habituation effects across all conditions, making the fourth and fifth trials less informative.) Within each condition, an initial ANOVA examined the effects of gender, color of first object shown (red first, green first), side of stage (left, right), and, when relevant, side of stage of first object in test trial display (left, right). In the Expected Color, Drop Color, and Add Object Only conditions there were no statistical effects for any of these factors. In the Add Color & Object condition, there were no significant main effects, but there were significant interactions between sex and familiarized object's color, between sex and the side of stage of the familiarized object in final test display, and between color of familiarized object and the side of stage of the familiarized object in the final test display. Given the small number of subjects in each cell, and the large number of tests, these findings must be interpreted with caution.

A repeated measures ANOVA with factors Trials (3) x Number Change (2) x Color Change (2) was conducted to determine the effects of trial as a within subjects factor and number change and color change as between subjects factors. The number change factor was set at one level (+1) for the Add Color & Object and Add Object Only conditions, and at a second level (-1) for the Drop Color and Expected Color conditions; the former conditions involved familiarizing infants with a single object, and testing them with displays of two objects, while the latter conditions involved both familiarizing and testing the infants with two objects. The color change factor was set at one level (+1) for the Drop Color and Add Color & Object conditions, and at a second level (-1) for the Expected Color and Add Object Only conditions. There were significant main effects of Trials, $F(2,88) = 11.208$, $p < 0.001$, and Number Change, $F(1,44) = 9.042$, $p = 0.004$, with no additional significant effects. Infants looked reliably longer on earlier trials than on later trials, and they looked reliably longer in conditions where there was a change in number. The effect of color change was not significant, $F(1,44) = 2.95$, $p = 0.093$.

Figure 3



Planned comparisons were subsequently carried out, yielding two significant results: infants in the Add Color & Object condition (+ number change, + color change) looked significantly longer than those in the Drop Color condition (- number change, + color change) [t(22) = 2.009, p = 0.029; Mann-Whitney U = 40, p = 0.033, one-tailed tests], and infants in the Add Object Only condition (+ number change, - color change), looked significantly longer than infants in the Expected Color condition (- number change, - color change), [t(22) = 2.452, p = 0.019, Mann-Whitney U = 34.5; p = 0.015, one-tailed tests]. The difference between infants in the Expected Color (- number change, - color change) and Drop Color (- number change, + color change) conditions was not significant [t(22) = 1.666, p = 0.110, Mann-Whitney U = 46; p = 0.133, two-tailed tests].

Discussion

Experiment 1 confirms that 12-month-old infants are sensitive to changes in number. There was a trend for color change, in the direction one would expect if the subjects were able to identify by color; however, in Hall & Leslie's (1995) original work, 12-month-olds clearly did not use color differences to identify physical objects; infants in their Drop Color Condition did not look longer than infants in their Expected Color Condition.

In any case, it is clear from Experiment 1 that 12-month-old infants do use color to *individuate* objects, since the babies in the Add Object Only condition clearly looked longer than the babies in the Expected Color condition. This pattern implies that babies in the latter condition expected only one object while those in the former expected two. However, the only criteria which the babies had for expecting two objects in the Expected color condition is the difference in color of the objects during the familiarization phase of the test trials. Just like adults, infants realize that two perceptual episodes, involving objects of different colors, involved two distinct individuals.

Why then did the infants not expect there to be two differently colored objects in the

Drop Color condition? A possibility consistent with object indexing theory is that, although infants can use difference in color to individuate objects, they do not automatically bind color properties to the object representations which they establish. In general, if two differently-featured objects are successively presented and the time delay between the objects' presentations is short enough, a novel feature in the second object may create a "pop-out" effect. This effect could be sufficient to motivate the creation of a second object representation (that is, the assignment of a second object index), without consulting the representation of the previously seen object. In fact, the first object's representation might contain only an object index, in which case it would not provide the information needed to discriminate the objects based upon physical features, especially if representing such featural information requires time and effort, and the first object was rapidly removed and then the second quickly presented.

It is important to note that adults will not always use gross featural changes to infer distinct individuals, so it is unreasonable to expect infants to do so automatically. There are many situations where, given appropriate spatiotemporal cues, adults will interpret successive displays as single objects undergoing featural changes, instead of as two distinct objects. For example many sortals allow dramatic featural changes over time, such as acorns growing into trees, or chameleons changing colors. Furthermore, many objects have different appearances when viewed from different angles. Finally, in artificial (laboratory) situations where a competition between featural and spatiotemporal cues to object identity is established, adults report the percept of a single object undergoing gross featural changes (Michotte, 1964). In such situations, interpreting the stimulus as containing two distinct objects requires subjects to infer abrupt discontinuities in the spatiotemporal paths of two objects, (either the disappearance of one object and the spontaneous appearance of another, or changes in the velocities of both objects, one from moving to still, and the other from still to moving). In our paradigm, however, there are two episodes involving distinct events, and each event involves objects undergoing abrupt changes in velocity. Interpreting the stimuli as containing one object or as containing two objects requires one to infer abrupt changes in spatiotemporal paths, but a single-object-interpretation also forces one to infer gross featural changes under a very short time interval; thus, the two object interpretation should be favored. In short, the object representations which infants initially create in response to our stimuli may not be very detailed, so that distinguishing properties may not be included. In this case, noticing a difference in color could motivate infants to create a separate object representation for a new item, and yet not include color in this representation.

As noted above, this possibility is consistent with *object indexing* theory. According to this theory, the results of Experiment 1 may be accounted for as follows: 12-month-olds are sensitive to color differences, and will assign new object indexes based upon the perception of a novel color. However, even in situations where object index assignment is driven by differences in color, infants may fail to bind color properties to these object indexes, so that they can not subsequently use color to identify the objects which are indexed.

Experiment 2 explores another aspect of the developmental hypothesis inspired by the object indexing framework. It investigates whether or not 9-month-olds who have individuated two objects by location will subsequently identify these objects by feature.

Experiment 2

Experiment 2 was closely modeled upon Experiment 1 with three crucial differences. First, objects were presented to infants simultaneously, instead of sequentially, during both the familiarization trials and the familiarization phase of the test trials. This change made it possible to test for identification by feature after individuation by location. Pulling both objects out together and placing them next to the screen provided the same type of spatiotemporal information which infants have used in other experiments to individuate objects (Wynn, 1992a; Baillargeon, Miller, & Constantino, 1994, Uller, Carey, Huntley-Fenner,& Klatt, 1994; Simon, Hespos, & Rochat, 1995; Xu & Carey, 1996). The question of interest here is whether infants who have used this spatiotemporal information to individuate objects will then identify objects by feature.

Second, Experiment 2 uses 9-month-olds instead of 12-month-olds. This was motivated by Xu & Carey's finding that 10-month-olds do not individuate by features. Third, Experiment 2 uses differently *shaped* objects (e.g. a circle and a triangle, both the same color) instead of differently colored objects. The third change was motivated by Hall & Leslie's (1995) finding that 12-month-olds successfully individuate and identify objects based upon shape.

As explained in the introduction, Xu & Carey's paradigm did not enable them to separate identification from individuation, since their unexpected outcome consisted of a single object. In Experiment 2, the unexpected outcome, like the expected outcome, contains two objects, but in the former case, one of the objects has been swapped with another, differently-shaped, object. (In addition, Xu & Carey used commonplace physical objects in their work, thus their objects differed among many featural dimensions including shape, size, color, etc.)

There are three conditions in Experiment 2: *Expected Shape*, *Drop Shape*, and *Add Shape*. The first condition is a control, where the objects shown during the test trials are exactly the objects shown during the familiarization trials. In the last two conditions, one of the objects shown during familiarization is replaced by a different object; in the Drop Shape condition one of the familiarization-objects is replaced by a duplicate of the other object. However, in the Add Shape condition, infants are familiarized to a display of two identical objects, and during the test trials, one of these two objects is replaced by a novel object.

Method

Subjects

Thirty-six full-term infants participated in this study (18 male and 18 female) with a mean age of 9;13 (ranging from 8;21 to 10;10). Equal numbers of infants (12) participated in each condition (mean ages 9;11, 9;14, and 9;15). The infants were recruited as in Experiment 1. Eight additional infants were tested and eliminated from the experiment due to fussiness (4), experimenter error (2), or observer error (2).

Materials and Apparatus

The same stage and posterboard screen used in Experiment 1 were used in Experiment 2. Eight wooden objects were used as stimuli; the four circles from Experiment 1 (two red and two green, 10 cm in diameter), and four wooden triangles, 10.5 cm tall with 11 cm wide bases. Two of the triangles were painted bright red and two were painted bright green, the same shades as the circles.

Design and Procedure

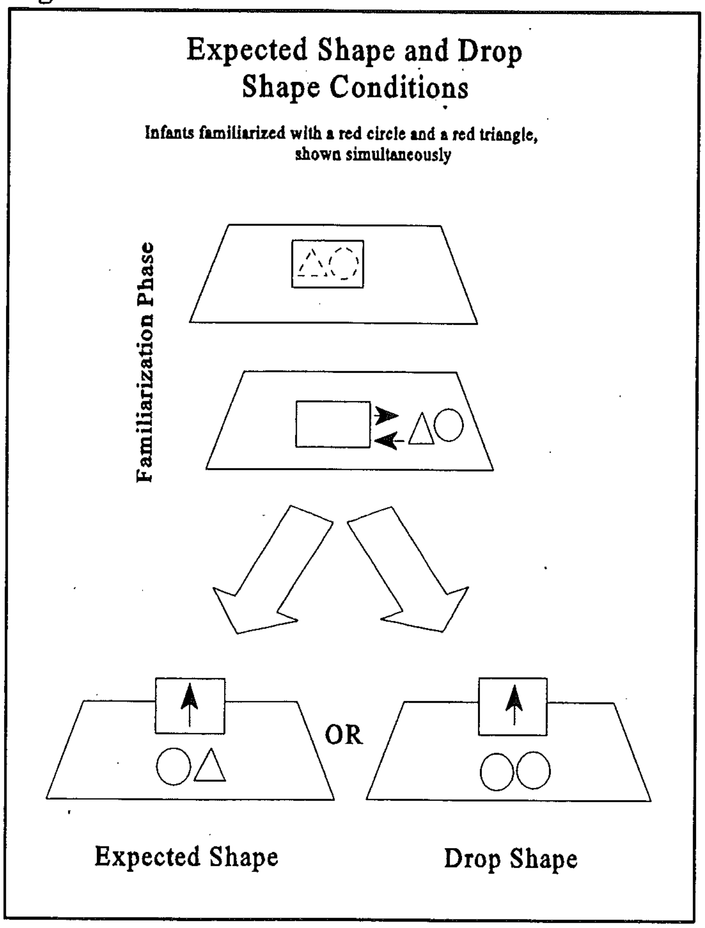
Equal numbers of infants participated in three conditions: Expected Shape, Drop Shape, and Add Shape. (See Fig. 4 for schematic representations of Expected Shape and Drop Shape, and Fig. 5 for a schematic representation of Add Shape.) The same recording procedure was used as in Experiment 1, with a single live observer watching a video monitor (with the top of the screen occluded), and pressing push-buttons connected to a 486 PC when the baby was looking at the stage.

Introductory Phase: As in Experiment 1, infants in all three conditions began with a greeting/calibration phase where the experimenter spoke to them and directed their attention to various places upon the stage. The introductory phase of Experiment 2 was exactly the same as the introductory phase of Experiment 1.

Familiarization trials: Expected Shape and Drop Shape conditions: Three identical familiarization trials were run in each of these conditions. The experimenter lowered her hand onto the stage behind the screen, pulled an object (e.g. a red circle) out from behind the screen, and placed it on the right side of the stage, next to the screen. Next, the experimenter pulled a second object (e.g. a red triangle) out from behind the screen and placed it next to the first. After about a second, the experimenter put the first object, then the second object, back behind the screen. (If the infant did not look at the objects after they were pulled out from behind the screen, the observer would signal to the experimenter, who would tap her hand, ring the bells on her wrist, or call out the subject's name to make sure the subject saw the object.) After another second, the entire sequence was repeated. (The experimenter pulled the objects out from behind the screen, left them in view for a second, and replaced them behind the screen.) After the second in/out sequence, the stage lights were turned off for three seconds, then relit, and the next trial was started. At the end of the third familiarization trial, the experimenter said to the parent "OK, this is the part where I'm going to ask you to close your eyes."

Test trials: Expected Shape condition: Five identical test trials were presented. Each began like a familiarization trial, with the familiarized objects (e.g. a red circle and a red triangle) both pulled out from behind the screen and then both returned behind it once. Next, the experimenter shook her hand to ring the bells, and grasped the top of the screen. As the experimenter began lifting the screen, she called out "Now" to signal to the observer to begin recording the baby's looking time. When the screen was removed, the two objects were revealed (e.g. the red circle and the red triangle), sitting next to one another at the center of the stage. The trial ended when the baby had looked away for two consecutive seconds, calculated by the computer from the observer's button-presses. When the trial ended, the computer turned off the stage lights, and the experimenter removed the objects, then set up the stage for the next trial. The color of the objects (red or green), the type of object which was

Figure 4

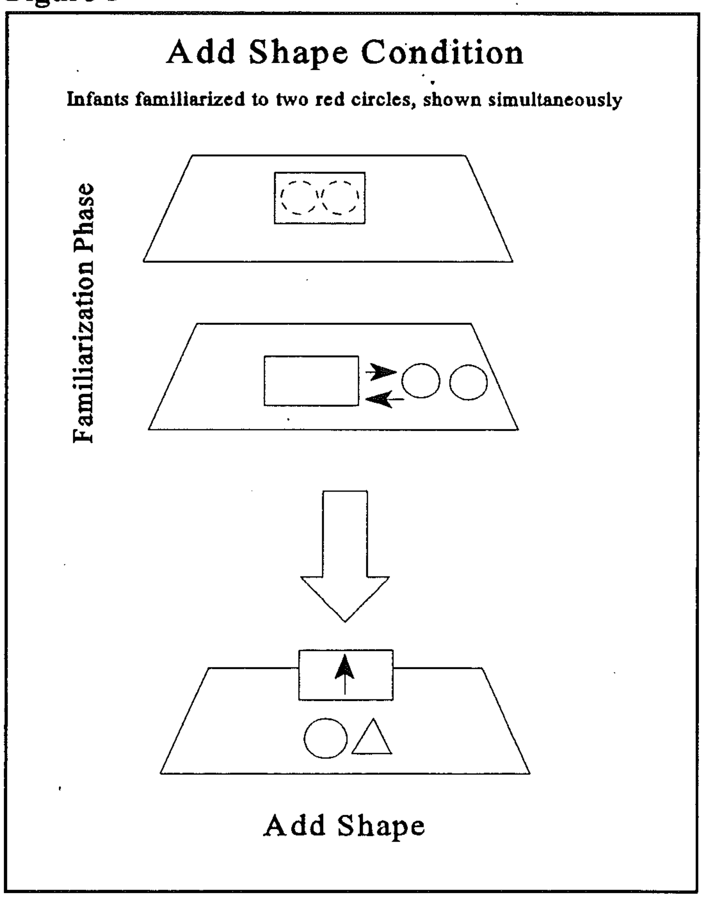


pulled out first, and placed on the right during the familiarization trials & familiarization phase of the test trials (circle vs triangle), and the side of stage where the "first-out" object was placed when the screen was removed (left vs right) were counterbalanced across subjects.

Test trials: Drop Shape condition: The test trials in the Drop Shape condition were exactly the same as those in the Expected Shape condition, except that when the screen was removed, there were two identical objects (identically-shaped and identically colored, e.g. two red circles) resting on the stage. This was arranged by using the door in the back wall of the stage to surreptitiously exchange one of the objects prior to lifting the screen.

Familiarization trials: Add Shape condition: The familiarization trials were the same as the familiarization trials in the previous two conditions with one crucial difference; instead of two differently-shaped objects, two identical objects (e.g. two red circles) were both pulled out from and then both put back behind the screen.

Figure 5



Test trials: Add Shape condition: As in the previous two conditions, there were five identical test trials, which began like the familiarization trials - first, the experimenter pulled out the two familiarized objects (e.g. two red circles), waited for about a second, and then put the objects behind the screen. Next, the experimenter shook her wrist to ring the bells, and grasped the top of the screen. The screen was removed to reveal two objects: one of the objects used during the familiarization trials and a second, differently-shaped (but identically colored) object (e.g. a red circle and a red triangle).

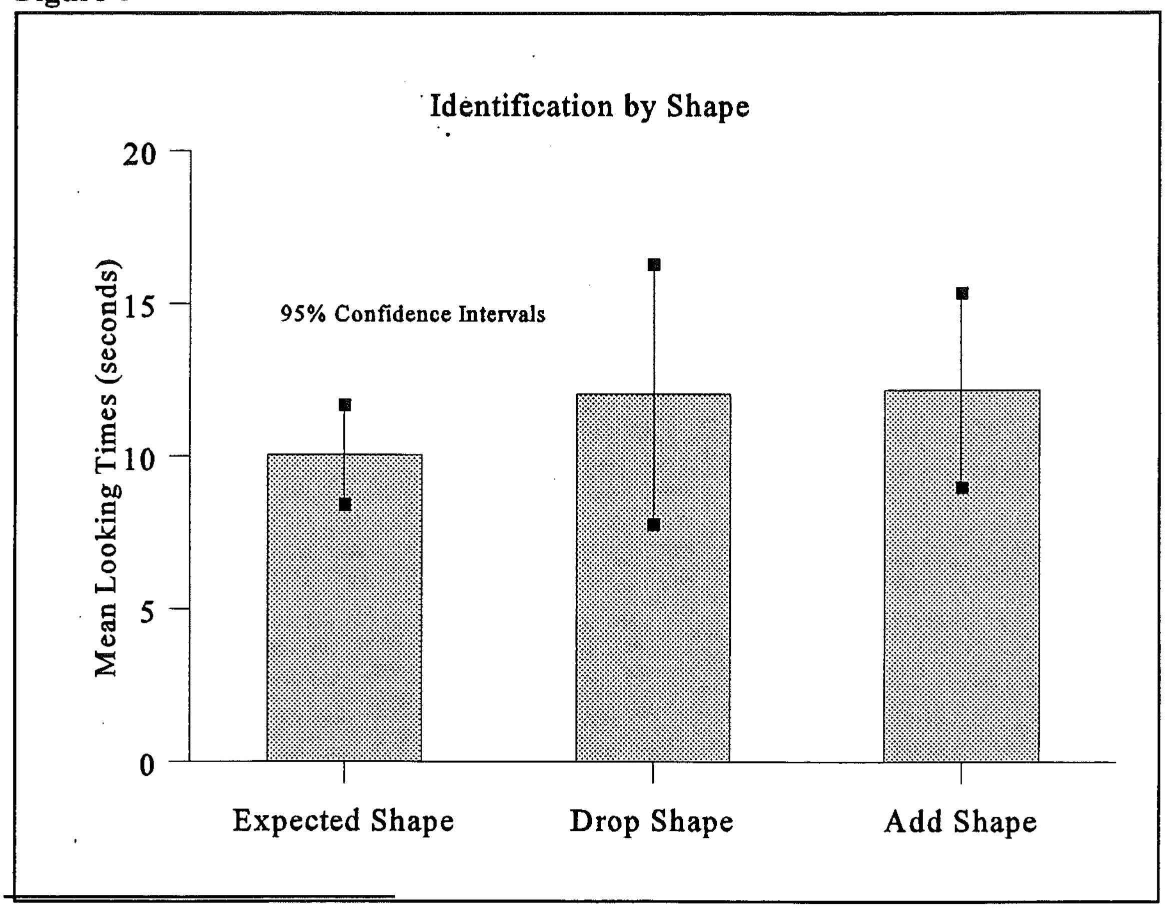
All of the 36 subjects were re-scored by a second observer, using the videotape made during the experimental session. Like the original observers, the second observers were blind to the condition because the top half of the monitor was occluded during the re-score sessions. For each trial, the percentage disagreement (the difference in times recorded by the primary and second observers divided by the time recorded by the primary observer) was calculated. The percentage disagreements were averaged over the trials and then subtracted from 100% to yield reliability scores. Inter-scorer reliability averaged 95%.

Results

Figure 6 presents the means of subjects' average looking times over the first three trials for each condition. Within each condition, an initial ANOVA examined the effects of gender, the shape of first object shown, and the side of stage where first object was located in the final test display. There were no statistical effects of any of these factors in the Expected Shape and Drop Shape conditions. However, in the Add Shape condition, there was a significant effect of gender, with the females looking longer than the males, and a significant interaction between gender and color of objects. This latter effect was probably an artifact of small cell sizes (n=3), however, since further ANOVAs conducted on average looking times with condition and sex as factors, and with condition and side of stage as factors yielded no significant interactions.[3]

A repeated measures ANOVA with factors Trials(3) x Condition(3) showed a significant effects of Trials, $F(4,132) = 10.87$, $p < 0.001$, with no other effects. Subjects looked longer on earlier trials than they did on later trials. A repeated measures ANOVA on average looking times (averaged over the first three trials) with factor Condition (3) indicated no significant differences among the three groups, $F(2,33) = 0.486$, $p = 0.62$. Non-parametric comparisons of the three groups also yielded no significant differences among them. (Comparing Drop Shape to Expected Shape: Mann-Whitney $U = 72$, $p = 1.0$; comparing Add Shape to Expected Shape: Mann-Whitney $U = 62$, $p = 0.564$.)

Figure 6



[3]The main effect of sex was due to the females in the Add Shape condition looking significantly longer than the males.

Discussion

Experiment 2 indicates that young infants may not always use physical features to individuate and identify objects the way adults do. In particular, this experiment suggests that 9-month-old infants, even when they are given sufficient spatiotemporal information to individuate two objects (the objects were shown to move independently when they were placed next to one another on the side of the stage), do not always use differences in shape to identify the objects. The results of Experiment 2 and some other recent empirical findings, taken together, may be used to construct a converging evidence argument in favor of the hypothesis that infants younger than 10.5 months old do not use physical features to individuate or to identify physical objects. However, some caution is advised since the evidence in favor of this conclusion, and particularly that young infants do not identify by feature, is not yet overwhelming. This will be discussed in more detail below.

The argument based upon converging evidence draws upon the work of Xu & Carey (1996) described earlier. Recall that Xu & Carey found 10-month-old infants who were presented with scenarios where two different objects were alternately taken out and replaced behind a screen would *not* look longer at outcomes where the screen was removed to display one object than at outcomes where the screen was removed to display the two different objects. Xu & Carey interpreted this finding as evidence that 10-month-olds do not identify by feature, but in fact, since their unexpected outcome differs in numerosity from the expected outcome their procedure may actually be interpreted as evidence that 10-month-olds do not individuate by feature.

On the other hand, elsewhere, Xu & Carey (in preparation) provide additional evidence that 10-month-old infants do not use features to individuate physical objects. In another experiment, they first familiarized their subjects with two different objects: a bright red fire engine and a rubber yellow duck, allowing the infants to handle each of these objects briefly. Next, infants were presented with a display where the duck sat on top of the toy fire engine. As they watched, a hand reached in and grasped the top of the toy duck. In the Expected condition, the duck was lifted up and held above the toy fire engine, which remained on the stage floor. In the Unexpected condition, the duck and fire engine were lifted up together as a unit and dangled above the stage floor. Xu & Carey report that there is not a significant difference in the looking times of the infants in these two conditions. It would appear, then, that the infants did not identify the objects in the test display with those with which they were familiarized; however, one may argue that their failure to identify the objects is a result of a failure to individuate them based upon distinct differences in features. In short, Xu & Carey provide evidence that infants do not always use featural information to individuate objects when adults would but their work is inconclusive concerning infants' use of physical features to identify objects.

Meanwhile, Simon, Hespos, & Rochat (1995) reported that 5-month-old infants who were shown an addition event involving two dolls being positioned behind a screen did not look longer at numerically correct outcomes in which one of the dolls had been "swapped" for a differently featured doll. Although this finding may be interpreted as evidence that 5-month-olds do not identify by feature, Simon et al.'s work is vulnerable to several objections. For example, it is possible that Simon et al.'s results are due to their subjects being especially interested in the featurally complex, attractive objects used in their counting experiments, so that the looking times were artificially elevated in all the conditions. Furthermore, if binding features to object representations is effortful, particularly for young infants, the infants may have not had enough time during Simon et al.'s test trials to construct sufficiently detailed object representations to distinguish among the two quite similar dolls. Experiment 2 controls for these possibilities by using very simple objects, differing only in shape properties. Hence, Experiment 2 shows clearly for the first time that even by nine months, infants do not identify pairs of objects by their features.

Unfortunately, one of the objections to Simon et al.'s work may be extended to Experiment 2. Although the objection was presented above as a criticism of the complexity of the objects, the key factor was *time*; infants may not have been capable of integrating featural properties into their representations of objects during relatively brief time intervals. In terms of Experiment 2, perhaps infants did not have time to bind shape properties during the course of the familiarization trials, or, more importantly, during the familiarization phase of the test trials. Across the three familiarization trials, each object was visible for a total of approximately 18 seconds, and the objects were both visible together for a total of approximately 12 seconds. However, these total times were broken into relatively short (2-3 second) intervals, interrupted by longer occlusion intervals. On each test trials, each individual object was visible for three consecutive seconds, and both were visible together for two consecutive seconds. It is possible that infants did not have time to re-identify the objects as those shown in the familiarization trials during these brief intervals. Furthermore, although the complexity of the objects was reduced in Experiment 2 relative to Simon et al.'s experiment, two objects were always displayed together in the former. Hence, two binding operations would have to occur in parallel, or in rapid succession. If the binding of featural properties is effortful, and infants are slower than adults, they may not be capable of binding features to object indexes in the 2-3 second intervals that objects are presented during the familiarization trials. If there is some minimum amount of time that infants need to bind features to object indexes, then infants may know that they have seen a particular set of features, but not have had time to bind them, and thus be unsure which features belong together. Future work will examine this possibility by testing for feature-conjunction errors in infants.

The results of Experiment 2, taken together with Hall & Leslie's (1995) finding that 12-month-old infants use differences in shape to individuate and identify physical objects, supports the hypothesis that infants use spatiotemporal properties prior to using featural cues to individuate and identify physical objects. More work remains to be done to answer the questions of when, and under what conditions, infants younger than 12 months old can use featural differences to identify physical objects.

General Discussion

The major result of these studies is the discovery that infants do not automatically identify objects by feature after individuating them—either by the same feature or by location. Experiment 1 reveals that 12-month-olds will individuate by color. The results of this experiment also provide weak evidence that they may be able to identify by color; however, previous findings are inconsistent with this evidence (Hall & Leslie, 1995). In addition, Experiment 2 suggests that 9-month-olds who have individuated two objects based upon spatiotemporal cues will not necessarily use featural differences to identify these objects.

Both these results are consistent with an object indexing-based account of attending to physical objects (Leslie et al., in preparation). According to this account, object indexes, which function like pointers and can be used to immediately access the items to which they point, are assigned to physical objects. The assignment of these indexes is typically driven by spatiotemporal cues for object individuation, so the indexes are generally assigned by location. However, at least in adults, gross featural differences can also drive the assignment of object indexes. Finally, object indexing posits that featural information is associated with object indexes through a non-default, perhaps effortful binding process.

It is this non-default binding process which enables object indexing to account for seemingly paradoxical situations where subjects individuate objects based upon a difference in features, yet not identify these objects based upon the same features. For example, object indexing theory would account for the results of Experiment 1 as follows: 12-month-old infants are sensitive to color differences among objects, and will use the introduction of a new color to motivate the assignment of an object index to the colored item. However, these infants do not automatically associate color information with the object indexes that they assign; thus, in Experiment 1, infants could know that they have seen two different objects because two indexes have been assigned, but they may not necessarily expect the objects pointed to by these indexes to have particular color properties.

Object indexing theory also allows that infants' abilities to individuate and identify physical objects may change over the course of their development; in fact, since this theory specifies that spatiotemporal information generally drives the assignment of indexes to objects, it predicts that individuation based upon spatiotemporal information may precede individuation based upon (differences in) featural properties. However, object indexing does not make any predictions about how the ability to use features to individuate and identity develops. There are several possible developmental sequences; for example, infants may first adopt the use of one feature as a criterion for individuation, later adopt it as a criterion for identification, and later still adopt another feature as a second criterion for individuation, then for identification, etc. Alternatively, features may be adopted as criteria for individuation all at once, or new features may be adopted before others have been accepted as criteria for identification.

Hall & Leslie's (1995) work, combined with the results of Experiment 1, suggests that shape may generally precede color as a criterion, and that the use of a feature to individuate can precede the use of the same feature to identify. If the former is true, it is possible that the 9-month-olds in Experiment 2 are at a point in their development where they treat shape in the same manner that 12-month-olds treat color; that is, although they do not use shape to identify, they may use shape to individuate. A replication of Experiment 1, using shape differences instead of color differences and 9-month-olds instead of 12-month-olds, is planned to investigate this.

Many other possibilities exist, however. Perhaps infants find certain types of features easier to encode, or maybe they preferentially attend to different sorts of features at different ages, depending upon other aspects of their cognitive development. For instance, 12-month-olds may not use color to identify objects in Experiment 1 because they are preferentially attending to shape. Attending to shape is important for learning nouns, and 12-month-old infants are typically at the stage where they are acquiring nouns (in terms of comprehension, not necessarily production). Interestingly, Xu & Carey (1996) report a correlation among 10-month-olds who succeed in individuating objects based upon shape and those whose parents report that the babies understand the words used to label the objects in their experiment. Perhaps the 12-month-olds in Experiment 1 even suppress color properties so that they can more easily bind shape properties to their object representations.

If so, it is possible that younger infants may individuate and identify by color and not by shape, since color is a highly salient property. Bornstein asserts that when infants *discriminate* objects, color is "as or more impressive than shape, number, or position." (1985; 79) Note that discriminating objects is more closely tied to object identification than object individuation; it does not involve setting up distinct individuals, but rather using featural differences to track the different individuals. Furthermore, Coldren & Colombo (1994) discovered that 9-month-old infants show a preference for similarity in color over similarity in form when they are presented with novel stimuli which dissociate the color and the form of a previously reinforced stimulus.[4] Future work will include a replication of Experiment 1

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[4]Coldren & Columbo's preferential looking experiment began when infants were shown a pair of stimuli that varied in both shape and color (for example, a green triangle and a blue circle). They reinforced the infants by playing a tape of a female voice whenever they directed their attention to one of two stimuli until the infants had learned to preferentially attend to the reinforced stimuli. In the test trials the two features were dissociated. (For example, a test trial for infants who were trained using a green triangle and a blue circle would contain a green circle and a blue triangle). In the first test trial, infants significantly preferred

with 9-month-olds, to test for a dissociation between the use of shape and the use of color to individuate and identify physical objects.

Turning now to Experiment 2, the results of this experiment imply that 9-month-old infants do not identify by shape, or more generally, that infants less than ten months old will not identify by feature. This produces a dilemma; previous infancy work has shown that young infants are sensitive to non-spatiotemporal properties of physical objects, and that they appear to form expectations based upon these properties. For example, in a groundbreaking experiment, Baillargeon, Spelke, & Wasserman (1985) habituated 4-month-old infants to the movement of an opaque screen rotating through 180 degrees, oriented such that the screen rotated towards and away from the infant. Once the infants were habituated to this display, an object was placed such that it would obstruct the rotational path of the screen. These infants looked much longer at "impossible" trials where the screen continued to rotate as it had prior to the object's placement (because the object was surreptitiously moved away), than at "possible" trials, where the screen stopped when it came into contact with the object. This work was then extended, using a sponge-like object in place of the rigid obstructing object. The infants were first familiarized with the spongy object, so that they had an opportunity to encode its properties. When this group of infants was habituated to the drawbridge display and tested on an event where the screen continued to rotate through 180 degrees in the presence of the object, they did not significantly recover interest; hence, these young infants must have formed a representation of the object which included it's "spongy" property.

Furthermore, Leslie (1984) demonstrates that 28-week- (~6.5-month-) old infants are

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stimuli the same color as the reinforced stimulus over stimuli the same shape as the reinforced stimulus. (That is, the proportion of looking time at the color-matched, differently-shaped object was significantly greater than .50).

sensitive to the difference between a human hand and another inanimate object. Leslie habituated two groups of infants to films showing a "pick-up" event; one group witnessed a hand picking-up a doll, and the other watched as an oblong white rectangular prism traced through the same movements as the hand, appearing to pick-up the same doll. After habituation, the infants were tested upon equivalent films which lacked contact between the hand (or prism) and the doll. Leslie reported that the infants in the hand condition recovered interest to the non-contact version (relative to controls who were shown the hand picking-up the doll again after habituation) significantly more than do the subjects in the prism condition (relative to the appropriate prism control). He suggested that "contact has a different 'value' for the infant in the hand pick-up event than in the other contexts (1984:29)." Since the pattern of motion of the prism was the same as that of the hand, this work implies that 6.5-month-old infants will form differing expectations based purely upon the featural differences between an human hand and a rectangular prism.

The experiments just described represent only a tiny fraction of a large body of evidence indicating that young infants (that is, infants less than 10 months of age) can encode non-spatiotemporal properties of physical objects, and will form expectations based upon these properties. One major difference between the two studies just described and the experiments described here, however, is that the former both used a habituation procedure, whereas the work presented here uses a violation-of-expectation paradigm, with a familiarization phase rather than a habituation phase. This difference is important since, as noted in the discussion section following Experiment 2, timing may play a crucial role. One can account for the results of Experiment 2 by positing a difference in the amount of time that infants and adults need to bind property information to object indexes. Furthermore, although

Simon, Hespos, & Rochat (1995), also used violation-of-expectation following familiarization, the structure of their familiarization trials was the presentation of a single event, during which their subjects had little time to simply observe the objects.

In contrast, Xu & Carey followed up their original experiment with a replication which included trials where the infants are allowed to look at the objects as long as they wish, and a habituation version of the original experiment. Hence, one can not object that the infants in their experiments did not have time to encode the properties of the objects. However, their procedure does not test for infants ability to identify by feature; the unexpected outcome involved a different number of objects than the expected outcome, so this procedure confounded individuation with identification.

In short, although Xu & Carey attribute differences in performance at different ages to the emergence of concepts of object kinds, and the results of Experiment 2 appear to support this hypothesis, the evidence produced up to this point does not warrant the conclusion that infants below 10.5 months can not use features to individuate and identify physical objects. This is especially true given the abundance of previous work indicating that young infants attend to, and form expectations based upon, non-spatiotemporal features of physical objects.

The evidence which appears to support Xu & Carey's conclusion does, however, indicate a primacy for spatiotemporal cues over physical features as criteria for individuation and identification. It simply leaves open the questions of when and how features are adopted as such criteria. It is possible that the procedure used in the experiments presented here is inappropriate for subjects younger than 12 months old, because the younger infants require more time to encode features than is provided.

The abilities to individuate and identify physical objects is a foundation of human intelligence, playing essential roles in cognition and reasoning. Recent work with human infants suggest that these abilities change over the course of development. It has been suggested that these changes may be due to the emergence of concepts of object kinds; however, it is also possible that these changes are due to developmental changes in the mechanisms responsible for object individuation. The work which is presented here represents an initial step in an exploration of these mechanisms. Many questions remain about the emergence of adult-like abilities to individuate and identify by feature, to be addressed through additional research.

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