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Bases for Object Individuation in Infancy: Evidence From Manual Search

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Two studies exploited a new manual search methodology to assess the bases on which 10- to 12-month-olds individuate objects. Infants saw 1 or 2 objects placed inside an opaque box, into which they could reach. Across conditions, the information specifying 2 objects differed. The dependent measures reflected persistence of reaching into a box that was empty regardless of whether an object should have remained. Success consists of little reaching after all objects are removed and persistent reaching for an object not yet retrieved. Given spatiotemporal information for 2 objects, both age groups succeeded. Given only property or kind information, only 12-month-olds succeeded. Despite disparate information-processing demands, this pattern converges with looking time data (Xu & Carey, 1996; Xu, Carey, & Welch, 1999), suggesting a developmental change orthogonal to that of executive function. This change may reflect the emergence of kind representations.

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Human adults individuate distinct physical objects accurately and virtually effortlessly. Furthermore, adults trace objects through time; they know which attended objects in a scene are identical to which of the objects viewed earlier. These abilities are central to human language and human action. Sentences are built by predicating properties of individuals, and, as we act on the world, we care which glass is ours, which object we already have retrieved, and whether all the cows that left the barn in the morning have returned.

Object individuation consists of determining the numerically distinct (distinct in the sense of *distinct one*) objects that articulate a given scene. Studies of object individuation in infancy typically concern the simplest individuation problem: establishing whether one single object or two distinct objects are involved in some event.[1] Adults bring a wide variety of information to bear on the task of object individuation, including spatiotemporal information (one object cannot be in two places at the same time), property information (a red plastic entity seen on one occasion is unlikely to be the same individual as a yellow cloth entity seen on another), and kind information (a dog cannot be the same individual as a table). Under many circumstances, spatiotemporal information is primary; if we see an entity radically change properties before our very eyes and maintain spatiotemporal continuity (think of children's "Gobots"), we interpret it as a single individual. Furthermore, in experiments on object tracking and apparent motion, spatiotemporal considerations rather than property identity determine the individuals seen (Burke, 1952; Kolers & von Grünau, 1976; Michotte, Thines, & Crabbé, 1964; Navon, 1976).

Many authors have suggested that for infants, also, spatiotemporal information is the earliest and most robust basis of object individuation (Bower, 1974; Xu & Carey, 1996; Xu, Carey, & Welch, 1999; see also Spelke & Van de Walle, 1993). Infants as young as 2.5 months appear to reason about the behavior of physical objects in a manner consistent with the constraint that objects trace unique, continuous paths through time and space (Spelke, Breinlinger, Macomber, & Jacobson, 1992). This spatiotemporal constraint on object behavior permits infants to individuate numerically distinct entities. For example, when no spatiotemporal boundary is seen to exist between two adjacent, fully visible surfaces, 5-month-old infants reach to the display as if for a single large object. In contrast, when the same two surfaces are shown to move independently of one another, infants reach as if to two distinct objects (Hofsten & Spelke, 1985; Spelke, Hofsten, &

[1]More generally, individuation and enumeration are related as follows: Enumeration presupposes individuals. Enumeration is a process that yields a representation of the number of individuals in a set. The reverse is not the case; it is possible to distinguish arrays with one object from arrays that contain two numerically distinct objects without creating a symbol for *one* or *two* (see Simon, 1997; Uller, Carey, Huntley-Fenner, & Klatt, 1999).

Kestenbaum, 1989). Infants also use spatiotemporal discontinuities to individuate objects in circumstances in which surfaces move into and out of sight. Five-month-old infants viewing objects emerging in alternation from the far edges of two spatially separated screens, with no object ever appearing in the middle, establish a representation of two objects (Spelke, Kestenbaum, Simons, & Wein, 1995; for a similar result with 10-month-olds, see Xu & Carey, 1996).

Often, however, spatiotemporal information is unavailable to individuate the objects in a scene or event. Sometimes, none of the adjacent surfaces in an array is moving. Furthermore, we sometimes see an object on successive occasions such that its spatiotemporal history either is unknown (e.g., a cup is seen on the table in the morning and then again in the evening) or ambiguous (e.g., a person leaves the room and then a person enters). Under these circumstances, we as adults rely on our vast knowledge of object kinds and their characteristic properties to help parse the array into individual objects. However, how do infants—for whom many object kinds are unfamiliar and for whom the contingent likelihood of property transformations are largely unknown—trace object identity under these circumstances? Currently, the answer to this question is not settled.

Xu and Carey (1996) addressed this problem using an adaptation of Spelke et al.'s (1995) paradigm. They found that whereas 12-month-old infants use both spatiotemporal information and kind or property information to individuate objects in a spatiotemporally ambiguous occlusion situation, 10-month-old infants succeed only when provided with unambiguous spatiotemporal information. In their experiments, infants were familiarized with an event in which an object emerged from and then disappeared behind one side of a single, central occluding screen, followed by a second object emerging from and disappearing behind the opposite side of the screen. The two objects were of distinct kinds, with contrasting properties (e.g., a gray rubber elephant and a red metallic car), and in the property/kind condition they were never seen together at the same time. Following familiarization, the screen was turned aside to reveal either two objects (possible outcome) or a single object (impossible outcome). Twelve-month-old infants overcame a baseline preference for two objects and increased their looking at the single object display. In contrast, looking patterns of 10-month-old infants were identical in both the experimental and baseline conditions. Results in a separate spatiotemporal condition suggest that it is not simply the overall difficulty of the task that underlies the behavior of the younger infants. In this condition, both objects were briefly fully visible simultaneously, giving unambiguous spatiotemporal evidence that two distinct objects were involved in the event. Under these circumstances, both 10- and 12-month-old infants succeeded.

In Xu and Carey's (1996) studies, infants younger than 12 months of age failed to use kind differences (e.g., the distinction between a car and an elephant or between a book and a bottle) or property differences (e.g., the distinction between a red, metallic, car-shaped entity and a gray, rubber, elephant-shaped entity) as a basis for inferring that two distinct objects were involved in an event. Xu et al. (1999)

provided convergent evidence for a change between the ages of 10 and 12 months in the ability to use kind or property information in object individuation. They found that whereas 12-month-olds correctly parsed a spatiotemporally ambiguous display of stationary adjacent objects (e.g., a duck on a car, a cup on a shoe) into two distinct entities, 10-month-olds failed to do so. However, 10-month-olds succeeded when shown that the two objects could move independently of each other.

In contrast, other closely related studies have found apparent success at an earlier age, challenging the claim that before the age of 11 to 12 months infants cannot draw on property or kind contrasts to individuate objects. For example, Wilcox and Baillargeon (1998a, 1998b) showed that infants as young as 4.5 months look longer at events in which a red ball disappears behind one edge of a narrow screen and then a blue box emerges from the other side than at comparable events in which the screen is wider. They interpreted this finding as reflecting infants' use of the differences between the objects to infer that two distinct objects are involved in the event. On this account, the narrow but not the wide screen event evokes longer looking because both objects could not simultaneously fit behind the narrow screen. Furthermore, Wilcox and Putthoff (1998) showed that infants as young as 5.5 months succeed in a version of Xu and Carey's original task in which the occlusion event and the objects involved are dramatically simplified. Similarly, Needham and her colleagues found that infants as young as 4.5 months of age individuate ambiguous stationary displays in the absence of spatiotemporal information under some conditions—for example, if the objects and display are simple (Needham, 1998; Needham & Baillargeon, 1998; for reviews, see Needham, 1997; Needham, Baillargeon, & Kaufman, 1997).

Across these studies, how is it possible to reconcile the apparent discrepancies in the age at which infants succeed at individuating objects? Wilcox and Baillargeon (1998a) noted that one way in which these studies differ from one another is with respect to the information-processing demands they place on infants. For example, to determine whether one object or two objects are implicated in the events, infants in Xu and Carey's (1996) task must construct a representation of one moving object that is being continuously occluded and disoccluded, hold that representation in mind, and compare it with a second moving object also undergoing repeated occlusion and reemergence. Furthermore, it has been proposed that it may be more difficult for infants to map a representation of an occlusion event onto a fully visible test display than simply to assess the consistency over time of a single continuous occlusion event (the distinction between *event mapping* and *event monitoring*; Aguiar & Baillargeon, 1997; Wilcox & Baillargeon, 1998a). The Wilcox and Baillargeon studies, in contrast, involve either event-monitoring tasks or simplified event-mapping tasks involving a single trajectory. Such differences may partially explain why infants appear to individuate objects in the absence of spatiotemporal information under some circumstances but not others. Representations of distinct individuals constructed on the basis of spatiotemporal evidence may be robust enough to withstand even rather substantial information-processing demands, whereas representations constructed on the basis of other differences between objects may be more fragile. On this account, heavy information-processing demands may differentially interfere with inferences based on these more fragile representations, causing the age of success on any particular task to be highly influenced by details of its information-processing demands.

A consequence of this analysis is that with *increased* information-processing demands, relative to those in Xu and Carey's (1996) task, infants even *older* than 12 months of age might be expected to fail to individuate objects in the absence of spatiotemporal information. One goal of the studies reported here is to explore this possibility.

Consider the following task. You are shown a box into which you cannot see. You see one object (e.g., a toy duck) removed from and replaced in the box and then another object (e.g., a telephone) removed from and replaced in the box. How many times do you reach into the box to remove objects? As in the Xu and Carey (1996) paradigm, you must hold a memory representation of the first object in mind and compare it to the second object to conclude that at least two objects are in the box. With respect to the information-processing demands in the part of the task in which representations of individuated objects are established, then, this task closely matches that of Xu and Carey (1996). However, with respect to the dependent measure, this task differs from any looking time task because no outcome whatsoever is visually available; there is no event mapping, let alone event monitoring. Infants must produce a solution actively, not simply assess the consistency of a visually presented test event. One of the most confirmed results in all of cognitive psychology is that recognition is easier than recall (e.g., Brown, 1965; Davis, Sutherland, & Judd, 1961; Heine, 1914; G. Mandler, Pearlstone, & Koopmans, 1969; McNulty, 1965; Rock, 1967; Wolford, 1971). Furthermore, the memory representation formed must support manual search rather than looking. Manual search measures of representations of hidden objects generally yield success at later ages than do looking time measures, as has been demonstrated repeatedly (e.g., Baillargeon & Graber, 1988; Baillargeon, Graber, DeVos, & Black, 1990; Diamond, 1985, 1991; Hofstadter & Reznick, 1996; Piaget, 1954). Compared to looking time tasks, a number of additional abilities needed in manual search tasks have been proposed, such as means-end processing (Willats, 1989), more robust representation of objects (Munakata, McClelland, Johnson, & Siegler, 1997), or development of prospective control of action (Bertenthal, 1996). Moreover, the disparity between success in looking time and manual search measures is not easily overcome; it extends well into the toddler years (Hood, Carey, & Prasada, in press). Taken together, such considerations suggest that an individuation task in which infants must manually search for each individual hidden object would place heavier demands on them than any looking time task employed to date.

The development of such a method is desirable for many reasons. Studies with looking times as the dependent measure provide very indirect evidence about how many objects the infant thinks are involved in the event. For example, consider the Wilcox and Baillargeon (1998a, 1998b) wide screen/narrow screen studies. Infants look longer at the events with the narrow screen. This result may, as Wilcox and Baillargeon proposed, this result may reflect infants' use of property/kind differences to infer the presence of two numerically distinct objects and their appreciation of the fact that the two objects could not fit behind the narrow screen. These findings are also consistent with a plausible alternative explanation. For adults, two entities that appear to have traced a spatiotemporally continuous path often are interpreted as a single object, despite changes in properties such as shape and color (Burke, 1952; Kolers & von Grünau, 1976; Michotte et al., 1964; Navon, 1976). Thus, infants may have looked longer in the narrow screen events because a single object was seen to change its properties (for evidence that adults perceive these events this way, see Carey & Bassin, 1997). On this alternative, young infants, like adults, would have the expectation that objects maintain properties over time and occlusion (Baillargeon, 1987; Baillargeon & Graber, 1987; Gibson, Owsley, Walker, & Megaw-Nyce, 1979), but the infants would not necessarily have the capacity to use property or kind differences as a basis for establishing a representation of numerically distinct individuals. The question of which interpretation, if either, is correct is not yet settled; here, we merely note that studies of object individuation must provide unambiguous evidence concerning the number of numerically distinct objects infants take to be involved in the target event. A manual search task could provide such evidence because, on the assumption that search is search for *an object,* patterns of search reflect the number of objects the child thinks are in the box.

In sum, the measure developed here has two goals: (a) to provide convergent evidence concerning developmental changes in information supporting object individuation using a different, and perhaps more direct, measure; and (b) to investigate the effects of increasing the information-processing demands on success in object individuation based on kind or property information.

Our method is based on that of Starkey (1992), who placed small numbers of objects into an opaque container and monitored how many times children between the ages of 18 months and 4 years reached in to retrieve them. In a preliminary study, we adapted Starkey's method directly (Xu, Carey, Raphaelidis, & Ginzbursky, 1996). Results were promising with 12-month-olds, but younger babies refused to reach at all in this study, and even the older infants often failed to search for the second object. We altered the procedure of the experiments reported here to ameliorate these difficulties. Most important, we incorporated a training period to encourage infants to reach. In addition, after infants retrieved each object, we took the object away. Under these conditions, infants often reach into the box again, regardless of how many objects are inside. However, in pilot testing some of these reaches appeared highly cursory, whereas others were more deliberate and searching. This observation led us to the method reported here, which combines the magic tricks of the looking time studies with manual search as the dependent measure.

Infants are shown a box into which they can reach but not see. On one-object trials, a single object is shown to infants and returned to the box, which is presented for reaching. Infants invariably retrieve the object, which is then taken away from them, after which reaching is coded. Because the object has been retrieved, reaching should be brief and cursory. On two-object trials, infants are shown two objects (either simultaneously in the spatiotemporal condition or successively in the property/kind alone condition). Before the box is presented for reaching, one object is surreptitiously removed. Again, infants invariably retrieve the object still in the box, which is then taken away from them, following which reaching is coded. Now, infants who have represented two objects should reach often and persistently because they should expect to find the second, missing object.

EXPERIMENT 1

Method

Participants

Sixty-four full-term infants participated in the study, 32 of whom were 10 months of age (range = 10 months, 1 day to 10 months, 26 days; mean age = 10 months, 11 days) and 32 of whom were 12 months of age (range = 12 months, 2 days to 12 months, 29 days; mean age = 12 months, 14 days). Infants were randomly selected from the lab's pool of participants. Some families were initially contacted by letter and follow-up phone calls from a commercially available list of parents living in the area. Others were recruited through brochures placed at local children's organizations (e.g., museums, gyms, pediatricians' offices) or handed out at playgrounds. The socioeconomic status (SES) of the resulting participant pool was predominantly middle class; ethnicity was predominantly Caucasian, although some were African American, Hispanic, Asian, or from the Pacific Islands. Half the infants in each age group were girls. Sixteen infants at each age were run in a spatiotemporal condition and 16 in a property/kind alone condition. Mean ages for each condition were the same as for the age group as a whole. Fourteen additional infants participated but were excluded from the analyses: 3 for refusal to reach at all during training and test, 4 for experimenter error, 1 for parent interference, and 6 for fussiness.

Materials and Apparatus

The box was 32 cm deep, 25 cm wide, and 12.5 cm tall and was made out of 1.3 cm-thick black foam core. The front face of the box had an opening 15 cm wide and 8 cm tall, which was covered with purple spandex material with a horizontal slit spanning the width of the opening. The back face of the box had an identical opening, which was covered entirely by a black felt flap.

The 10 objects (4 training objects and 6 test objects) used in the study were small graspable toys that infants would find attractive. They were all approximately the same size but differed dramatically in kind, as well as in properties such as shape, color, and texture. The training objects consisted of a Cookie Monster finger puppet, a miniature doll's bottle, a toy leopard, and a miniature juicer. The test objects were a toy telephone, a small book, a wind-up globe with feet, a toy car, a Mickey Mouse, and a toy helicopter.

The infant sat in a high chair placed at a small table. A curtain hung from the edge of the table so that the infant could not see the objects on the floor beneath. The experimenter knelt to the infant's left. A microcamera mounted in a black backdrop to the infant's right recorded reaching behavior. A VHS video camera placed approximately 1.5 m in front of the infant recorded his or her face.

Design

The experiment consisted of two conditions: a *spatiotemporal condition* and a *property/kind alone condition*. In the spatiotemporal condition, infants saw both objects together at the same time; in the property/kind alone condition, the objects were removed from the box one at a time. Although property and kind information was available in both conditions, the spatiotemporal condition is so named because only in this condition did unambiguous spatiotemporal evidence as well as property/kind information specify the number of objects. Sixteen infants at each of the two ages were randomly assigned to each of these conditions. The experiment began with a training phase in which infants were taught to reach into the box to retrieve objects. The training phase consisted of 2 one-object trials and 2 two-object trials, presented in the order 1, 2, 2, 1 or 2, 1, 1, 2. Training was immediately followed by a test phase that also consisted of 2 one-object trials and 2 two-object trials, presented in the order 1, 2, 2, 1 or 2, 1, 1, 2. Order of presentation was completely counterbalanced across both training and test in both conditions.

Procedure

First pair of training trials. The Cookie Monster puppet was always paired with the bottle and the toy leopard with the juicer for the two-object training trials. One object in each pair also served as the single object in the one-object trial for that pair. The first training pair served both to introduce the box and to familiarize the infant with the numerosities that would be encountered in subsequent test trials. Before the first trial, the experimenter introduced the box to the infant by placing her hand through the slit and into the empty box. The infant was encouraged to do the same. After the infant reached into the box, it was removed.

For the first one-object training trial, the experimenter placed the box on the table's edge, out of the infant's reach. She reached through the slit and removed the object, placing it briefly on top of the box before giving it to the infant to play with for 10 sec. She again briefly placed the object on top of the box before putting it back inside, protruding partially through the slit to encourage infants who were not inclined to reach. She slid the box toward the infant for reaching and cheered when he or she grasped the object. After the infant played with the toy for about 10 sec, the experimenter took the toy away. The box remained within reach for an additional 5 sec. If the infant reached during this period, the experimenter frowned and said, “There's nothing in there, it's empty.” Regardless of the infant's reaching action, the experimenter shook the box after 5 sec to show that it was empty and moved the box under the table.

For the first two-object training trial, the experimenter placed the objects side by side on top of the box. She gave the infant the first object for 10 sec, and then she returned it to the box top and gave the infant the second object. After 10 sec, the experimenter placed it back beside the first object. She then put both objects back in the box simultaneously, allowing a portion of each to remain visible through the slit. She pushed the box toward the infant and asked him or her to retrieve both toys. Ten seconds after the infant had retrieved the first object, it was taken. He or she was encouraged to retrieve the second object, as well. If the infant failed to reach within 10 sec, the experimenter retrieved the object from the box and gave it to the infant. Again, 10 sec were allotted to play before the object was taken. The box remained within reach for an additional 5 sec, following which the experimenter shook the box to show it was empty. If reaching occurred during this interval, the experimenter frowned and told the infant that the box was empty.

Second pair of training trials. The second training pair differed somewhat from the first. First, the objects were not visible when infants were asked to reach. In addition, the second training pair structurally resembled the test trials in terms of the number of times an object emerged from the box and the amount of time a given object was seen by the infant. The test trials are described in detail subsequently. The second training pair differed slightly from the test trials in two ways: (a) The infant always found the second object on two-object training trials, and (b) the experimenter used verbal encouragement to get the infant to reach if he or she was not inclined to do so.

Test trials. Each object used during the four test trials was unique, for a total of six test objects. The first two test trials and the last two test trials formed pairs. In each pair, each of the three objects was presented alone (for a one-object trial) to one third of the babies and was presented coupled with one of the two remaining objects to the rest of the babies, resulting in a total of three test pair orders. The telephone, book, and globe always appeared in the first pair of test trials, and the car, Mickey Mouse, and helicopter appeared in the second pair of test trials. On the two-object test trials, one of the toys was temporarily removed from the rear of the box so that after the infant had retrieved the first object, he or she would be reaching for an object that was not, in fact, there. The toy that was removed was counterbalanced across infants so that half the time it was the toy last presented and half the time it was the toy first presented. The procedures for the spatiotemporal and property/kind alone conditions are described subsequently.

In designing the test trials, our goal was to give infants ample opportunity to view each object and encode its features but not to make the objects so familiar that they were no longer interesting. Therefore, the object(s) were presented three times during each trial. On the first and last presentations, the experimenter placed the object(s) on top of the box so infants could see but not play with them. Only on the second presentation were infants allowed to explore the objects both manually and visually. The trials also were designed so that the number of appearances of objects (either the same object all the time on one-object trials or two different objects on two-object trials) was equated across both one- and two-object trials and across the two conditions.

Spatiotemporal condition. For the one-object spatiotemporal trial, the experimenter placed a single object inside the box out of the infant's view and then positioned the box on the far side of the table in front of the infant. For the first presentation, she reached through the slit and removed the object, placed it on one side of the box top for a moment, and returned it inside the box. She then repeated this sequence, placing the object on the opposite side of the box top. For the second presentation, the experimenter removed the object, placed it on one side of the box top for approximately 1.5 sec, and then handed it to the infant. After 10 sec, she returned the toy to the box top in the same location for a second or so and then placed it back inside the box.[2] She then repeated this sequence, placing the object on the other side of the box top. For the third and final presentation, the experimenter repeated the sequence of events previously described in the first presentation.

She then said, "Now it's your turn!" and slid the box toward the infant. After the infant retrieved the toy, the experimenter let him or her keep it for about 10 sec before taking it away and placing it on the floor. The box was left in place for another

[2]For the most part, infants readily relinquished the objects at the end of all 10-sec play periods. On the rare occasions when the infant did not, the experimenter quickly wrested the object from the infant's hand. On no occasion did it take more than an additional second or so for the experimenter to retrieve the object.

10 sec, during which the experimenter smiled at the infant. If reaching occurred during this interval, the duration of the reach was recorded. The box was removed after this period and the trial ended, unless the infant was in the process of reaching into the box. In that case, the box was left in position until the infant removed his or her hand from the box.

For the two-object spatiotemporal trial, the experimenter placed two novel toys inside the box out of view of the infant. On the first presentation, she placed the box at the far side of the table, brought out one object, and placed it on one side of the box top. She then removed the second object and placed it beside the first on the other side of the box top. The experimenter grasped both of the objects at once and put them back inside the box. On the second presentation, the experimenter removed the first object, placed it in its original location on top of the box for approximately 1.5 sec, and then handed it the infant for play. After 10 sec, she returned the toy briefly to the box top and then placed it back inside the box. Her hand reemerged with the second toy, and she repeated the sequence, except that the second toy was placed on the other side of the box top. On the third presentation, the experimenter repeated the sequence described for the first presentation.

After having covertly removed one of the two objects from the back of the box, the experimenter presented the box to the infant, saying, “Now its your turn!” After the infant retrieved the object that remained from the box, the experimenter let him or her keep it for 10 sec and then took it away. The box remained in position for an additional 10 sec. If the infant reached again during this interval, the duration of the reach was recorded. The experimenter then reached into the box, extracted the missing object that had been secretly replaced, and gave it to the infant to play with for 10 sec, after which it was taken away. The box again remained stationary for 10 sec (or until the infant removed his or her hand from the box, as described previously), after which the trial ended.

The second pair of trials was conducted in the same manner with three new objects.

Property/kind alone condition. The one-object property/kind alone trial was identical to that described for the spatiotemporal condition.

The two-object property/kind alone trial was almost identical in structure to the two-object spatiotemporal trial, except the infant never saw the two objects together at the same time. The experimenter placed the box on the table, took one object out of the box, placed it briefly on one side of the box top, and returned the first object to the box, removing the second object at the same time. After placing it briefly on top of the other side of the box, she put the second object back into the box. The first object was again removed, placed on its side of the box top for about 1.5 sec, and given to the infant for 10 sec. It was again placed briefly on the box top and returned inside the box. The experimenter removed the second object as her hand reemerged, placed it on its side of the box top, and gave it to the infant to play with for 10 sec. The second object was again placed on top of and then inside the box. The third presentation repeated the sequence for the first presentation. The objects were never simultaneously visible at any time during the procedure.

The experimenter then presented the box to the infant for reaching following the same procedure as for two-object trials in the spatiotemporal condition described previously.

Dependent Measures

Two dependent measures were coded and analyzed: the total duration of searching inside the box and the number of reaches into the box. Although these measures are correlated (infants who reach more often will also tend to have longer search durations than infants who reach less frequently), they are not identical. Indeed, an analysis of all trials during which at least one reach occurred reveals that this correlation is only moderate (Spearman's r = .46). Therefore, both are reported subsequently. On one-object trials, reaching behaviors were coded from the time the infant retrieved the first object through the 10-sec period after the experimenter had taken the object away (or until the infant removed his or her hands from the box, as described previously). These intervals are referred to as *one-object/expected outcomes* because the box should be empty following retrieval of the object, and the box is, in fact, empty.

On two-object trials, reaching behaviors were coded for two periods. The first interval was the time following retrieval of the first object through the 10-sec period after the experimenter had taken the first object away (or until the infant removed his or her hands from the box). These intervals are referred to as *two-object/unexpected outcomes* because although a second object should have been in the box, the box was, in fact, empty. The second interval was the time following the experimenter's retrieval of the second, missing, object through the 10-sec period after which the experimenter had taken the object away (or until the infant removed his or her hands from the box). These trials are referred to as *two-object/expected outcomes.* The box should now have been empty because both objects had been removed from it, and, in fact, the box was empty.

For both measures, infants' activity was defined as reaching so long that the knuckles joining fingers to hands passed through the slit in the front of the box. Reaches ended when the infant's knuckles reemerged from inside the box. Both measures were coded from the video record by an observer who was unaware of both the infant's condition (spatiotemporal or property/kind alone) and the outcome type (one-object/expected, two-object/unexpected, or two-object/expected outcome). The observer coded search durations by depressing a button box connected to a microprocessor using software designed to record looking time data (Pinto, 1995). On very rare occasions, some infants became distracted during a reach and their attention became clearly focused elsewhere although their hands remained in the box. Such intervals were excluded from the search duration measure. For the number-of-reaches measure, a single reach was defined as a continuous period in which the infant's knuckles had passed through the slit at the front of the box and ending when the knuckles reemerged. Grabbing the front edge of the box or the fabric covering the opening did not count as a reach for either measure. A second observer independently coded the number of reaches for 63 of the 64 infants. Agreement was good (r = .86). A second observer also independently coded duration of reaching during test trials for 52 of the 64 infants; interobserver reliability (calculated as the proportional difference between the primary and secondary observers) was high, averaging 91.5%. All results reported subsequently are based on the primary observer's data.

Results

Number of Reaches

Figure 1 depicts the mean number of reaches during the test trials for infants in each age group and each condition. Separate preliminary analyses of variance (ANOVAs) investigated the effects of gender, familiarization order, test trial order, whether the first or second object was withheld on two-object trials, and the particular pairings of test objects used for each infant. These analyses revealed a four-way interaction between gender, age, trial set, and condition, $F(1, 56) = 5.02$, $p < .05$, resulting from rather disparate reaching on the two sets of trials by 12-month-old girls in the spatiotemporal condition (Set 1 $M = 6.33$, $SE = 1.79$; Set 2 $M = 1.99$, $SE = 0.46$), whereas all other groups of infants showed approximately comparable reaching across sets. There was also a three-way interaction between familiarization order, condition, and outcome type, $F(2, 112) = 3.76$, $p < .05$, reflecting slight differences in reaching patterns across the two familiarization orders and conditions. There were no other significant main effects or interactions. Because the two findings reported previously are very likely a result of chance variation and were not replicated in the number-of-reaches measure or in Experiment 2, subsequent analyses collapsed across these variables.

To determine whether infants' frequency of reaching differed on the various outcome types in each condition, a 2 (age) × 2 (condition) × 2 (trial set) × 3 (outcome type) ANOVA was conducted, with outcome type and trial set as within-subjects variables. The analysis revealed a main effect of age, $F(1, 60) = 10.68$, $p < .005$, resulting from the fact that older infants reached more frequently overall ($M = 5.03$, $SE = 0.43$) than younger ones ($M = 3.17$, $SE = 0.36$), and a main

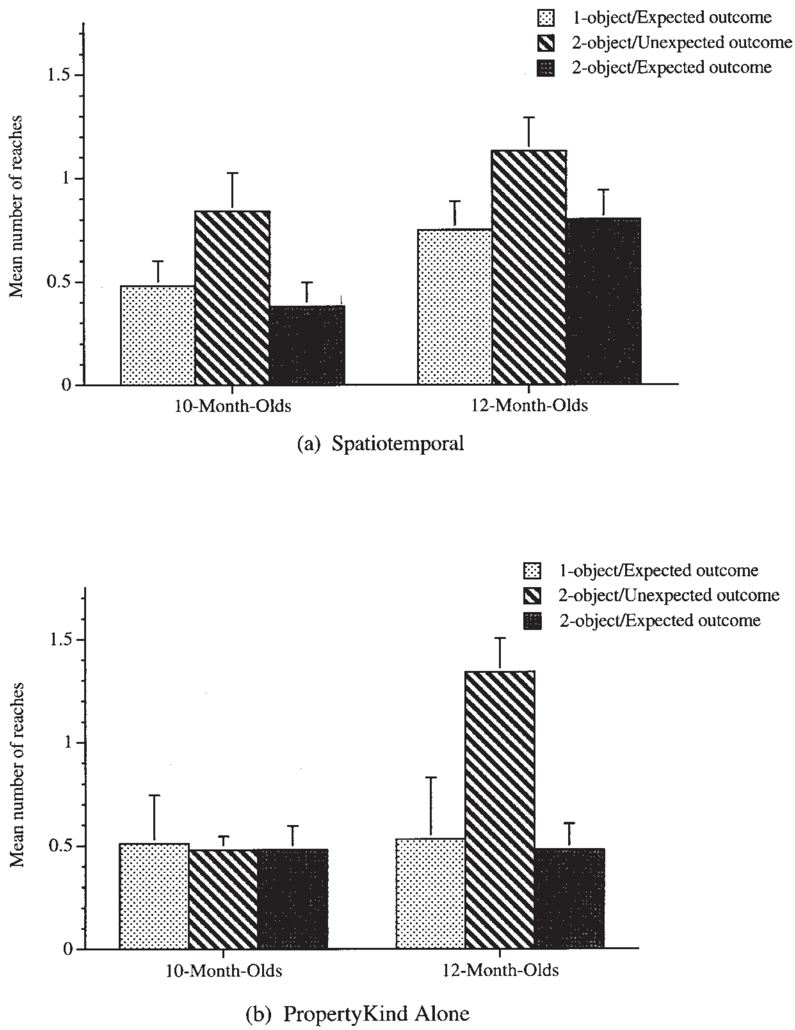

FIGURE 1 Mean number of reaches into box on one-object/expected, two-object/unexpected, and two-object/expected trials for 10- and 12-month-old infants in Experiment 1.

effect of trial set, $F(1, 60) = 4.94$, $p < .05$, indicating that infants reached more often on the first set of trials ($M = 2.30$, $SE = 0.22$) than on the second set ($M = 1.80$, $SE = 0.15$). There was also a main effect of outcome type, $F(2, 120) = 16.52$, $p < .001$. Infants reached more frequently on the two-object/unexpected outcomes ($M = 1.90$, $SE = 0.17$) than on the one-object/expected outcomes ($M = 1.14$, $SE = 0.12$) or the two-object/expected outcomes ($M = 1.07$, $SE = 0.13$). In addition, there was a significant interaction between age and outcome type, $F(2, 120) = 4.06$, $p < .05$, which can best be interpreted in light of a significant three-way interaction between condition, age, and outcome type, $F(2, 120) = 5.56$, $p < .01$ (see Figure 1). Nonparametric analyses confirm the overall pattern of reaching. Forty-six of the 64 infants reached as frequently or more frequently on two-object/unexpected than one-object/expected outcomes, and 49 reached as frequently or more frequently on two-object/unexpected than two-object/expected outcomes (Wilcoxon $z = 3.90$ and 4.12 respectively, both p's $< .001$).

To clarify the three-way interaction, separate 2 (age) × 3 (outcome type) repeated measures ANOVAs with age as a between-subject factor and outcome type as a within-subjects factor were conducted on the spatiotemporal and property/kind alone conditions. In the spatiotemporal condition, the ANOVA revealed a marginally significant main effect of age, $F(1, 30) = 3.89$, $p < .06$, indicating that older infants tended to reach more frequently overall ($M = 5.35$, $SE = 0.72$) than did younger infants ($M = 3.40$, $SE = 0.68$). The ANOVA further revealed a main effect of outcome type, $F(2, 60) = 8.52$, $p < .002$. Infants reached differentially across outcome types (Figure 1a). Preplanned Helmert contrasts indicated greater reaching on two-object/unexpected outcomes than on the average of the two expected types of outcomes, $F(1, 30) = 14.77$, $p < .002$, whereas one-object/expected outcomes did not differ significantly from two-object/expected outcomes, $F(1, 30) < 1$, *ns*. There was no interaction between age and outcome type, $F(2, 60) < 1$, *ns*, indicating that infants at both ages showed the same differential pattern of reaching. No other main effects or interactions were significant. Again, nonparametric analyses confirm this pattern. Twenty-seven of the 32 infants reached as frequently or more frequently on two-object/unexpected than on one-object/expected outcomes, and 28 reached as frequently or more frequently on two-object/unexpected than on two-object/expected outcomes (Wilcoxon $z = 3.10$ and 2.85, respectively, both p's $< .005$).

In the property/kind alone condition, the analysis revealed a main effect of age, $F(1, 30) = 10.00$, $p < .005$, indicating that older infants reached more frequently ($M = 4.71$, $SE = 0.49$) than did younger infants ($M = 2.95$, $SE = 0.26$). It further revealed both a main effect of outcome type, $F(2, 60) = 8.08$, $p < .002$, and a significant interaction of age with outcome type, $F(2, 60) = 8.43$, $p < .002$. The pattern of reaching differed across the two age groups in the property/kind alone condition (Figure 1b).

To clarify this interaction, separate ANOVAs were performed on outcome type for each age in the property/kind alone condition. Twelve-month-old infants reached differentially on the three outcome types, $F(2, 30) = 12.50$, $p < .001$ (Figure 1b). Preplanned Helmert contrasts revealed that infants reached more on two-object/unexpected outcomes than on the average of the two types of expected outcomes, $F(1, 15) = 21.57$, $p < .001$. One-object/expected outcomes did not differ significantly from two-object/expected outcomes, $F(1, 15) < 1$, *ns*. Nonparametric analyses fully corroborate these findings. Twelve of the 16 infants reached more frequently both on two-object/unexpected outcomes than on one-object/expected outcomes and on two-object/unexpected outcomes than on two-object/expected outcomes (Wilcoxon $z = 2.75$ and 3.13, respectively, both p's $< .01$).

In contrast, 10-month-olds in the property/kind alone condition did not reach differentially across outcome types, $F(2, 30) < 1$, *ns* (Figure 1b). Nonparametric statistics support these findings. Only 4 out of the 16 infants reached more often on two-object/unexpected outcomes than on one-object/expected outcomes, and only 7 reached more often on two-object/unexpected outcomes than on two-object/expected outcomes (Wilcoxon z's < 1, *ns*).

Search Duration

The pattern of results with the searching time measure was virtually identical to that of the number-of-reaches measure. Details of the ANOVAs and nonparametric analyses for both experiments are available from Gretchen A. Van de Walle. Here, we merely state the results qualitatively.

Figure 2 depicts the mean duration of searching the empty box for each type of outcome for infants in each age group and each condition. In the spatiotemporal condition, infants at both ages differentiated the outcomes, searching longer when a second object should have been in the box (two-object/unexpected outcomes) than when the box should have been empty (one-object/expected and two-object/expected outcomes). In the property/kind alone condition, however, only the older infants differentiated the outcomes. Ten-month-old infants failed to search longer when there should have been a second object in the box than when the box should have been empty.

Discussion

Despite the substantial increase in information-processing demands placed on infants in the manual search task, the pattern of findings obtained in Experiment 1 is entirely consistent with the data from two different looking time procedures (Xu & Carey, 1996; Xu et al., 1999). Twelve-month-old infants individuate objects in the current task when provided with either property/kind information alone or property/kind information paired with spatiotemporal information. They reach both more frequently and for a longer duration when a second object should be in the box than when the box should be empty. Ten-month-old infants, in contrast, individuate objects in this task only when provided with unambiguous spatiotemporal information that specifies two objects. Shown a telephone and a book withdrawn from and then replaced into a box, one at a time, 10-month-old infants fail to search for the second object after they have retrieved the first.

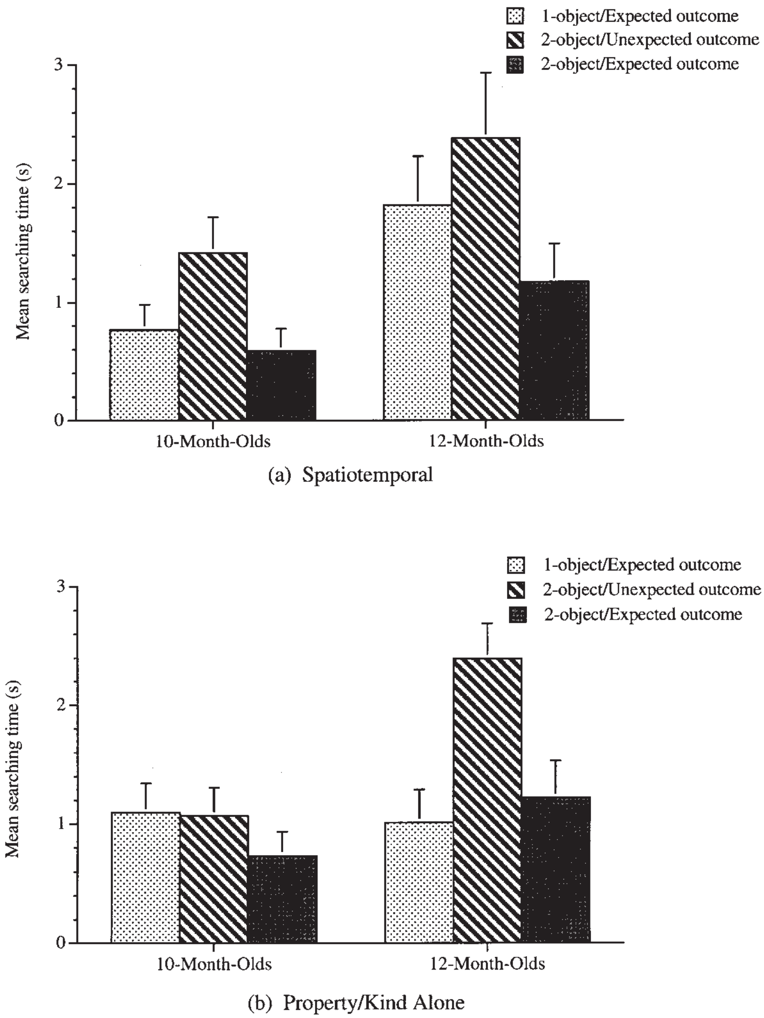

FIGURE 2 Mean duration of searching into box on one-object/expected, two-object/unexpected, and two-object/expected trials for 10- and 12-month-old infants in Experiment 1.

This conclusion depends on the assumption that success on this task reflects object individuation—that more persistent reaching for the second object on two-object trials reflects representations of numerically distinct objects. However, it is possible that success has quite a different source. Suppose that infants form a representation of just one of the objects, the sole object shown on one-object trials and a preferred object on two-object trials. Suppose also that infants search until the represented object has been retrieved and then lose interest in what is in the box. All infants would retrieve the represented object on the first reach of one-object trials. Only approximately half the infants would retrieve, by chance, the represented object on the first reach of two object trials. Thus, on half of the two-object trials, infants would be motivated to reach further. The data obtained on this “one-represented-object” account would be essentially indistinguishable from the data obtained, at least for the 12-month-olds. However, 10-month-old infants’ failure in the property/kind alone condition casts doubt on this alternative explanation for success in Experiment 1. The one-represented-object hypothesis predicts success regardless of whether spatiotemporal information was available.

Experiment 2 was designed to examine the one-represented-object account of 12-month-old success. We sought further evidence that this method is sensitive to representations of numerically distinct objects. In Experiment 2, spatiotemporal evidence for individuation is provided, but the two objects on two-object trials are physically identical to each other (e.g., two identical ducks). If the one-represented-object explanation is correct, infants should not differentiate one-object from two-object trials, for they will always retrieve the represented object on the first reach. However, if their persistent reaching for the second of two objects on the two-object trials is driven by a representation of exactly two objects in the box, they should succeed in Experiment 2.

Experiment 2 had a second goal: method improvement. Observation of the infants in Experiment 1 led us to suspect that the presentation of the objects was longer and more confusing than necessary. Therefore, we simplified and shortened the entire procedure.

EXPERIMENT 2

Method

Participants

Sixteen full-term 12-month-old infants participated in the study (range = 12 months, 3 days to 12 months, 27 days; mean age = 12 months, 13 days), half of whom were girls. Participants were recruited exactly as described in Experiment 1. The SES and ethnicity of participants were similar to those of participants in Experiment 1. Three additional infants participated but were excluded from the analyses: 1 for equipment failure, 1 for parent interference, and 1 for fussiness.

Materials and Apparatus

The materials and apparatus were identical to those described in Experiment 1, with the following exceptions. The familiarization stimuli used in Experiment 2 consisted of a set of plastic keys, a pair of small shoes, and a pair of plastic tigers. The test stimuli consisted of four identical pairs of objects: telephones, toy cars, toy books, and toy ducks.

Design

The design of Experiment 2 was almost identical to that of Experiment 1, except for four changes intended to speed up the procedure and keep infants' attention focused on the information that specified the number of objects in the box. First, a single initial trial was added prior to training to encourage reaching, and the number of training trials was reduced from two pairs to one. Second, during presentation, the objects were removed from and replaced into the box only once. Third, infants were not allowed to handle the objects during presentation; rather, the objects were presented only visually. Fourth, after their retrieval from the box, all objects were taken from infants after 5 sec rather than 10 sec.

Procedure

Initial trial. Once the infant was seated at the table, the experimenter placed the box on the table. She showed the infant a set of plastic keys, which she then placed partially into the box. The infant was encouraged to retrieve the keys until he or she did so. The box was then removed.

Training trials. The training trials followed the design of Experiment 1, modified as outlined previously. The shoe or shoes were always used in the first training trial and the tiger(s) in the second. The experimenter placed the object(s) only partially into the box so that part of each was protruding on only the first training trial, regardless of whether it was a one- or a two-object trial. Objects were presented for one 3-sec presentation and never given to the child to handle. On one-object trials, the object was not returned to the box after the first presentation but was slid from one side of the box top to the other (to equate number of hand motions across trial types). On two-object trials, both objects were withdrawn at once from the box and placed on either side of the box top. They also were returned to the box in a single motion. Finally, after infants retrieved each object, the experimenter allowed only 5 sec for play before it was taken away.

Test trials. Each of the four kinds of object was used equally often in one- and two-object trials, and each kind of object appeared equally often in each of the four ordinal trial positions in a Latin Square design. The test trials followed the same procedure as the spatiotemporal condition of Experiment 1, with the same exceptions described previously for training.

Dependent Measures

The dependent measures and analyses for Experiment 2 were identical to those of Experiment 1. Interobserver agreement for search duration, scored and calculated as in Experiment 1, from the video record for 13 of the 16 babies was high, averaging 94.6%. Agreement for the number-of-reaches measure, calculated over all 16 infants, was also high (r = .91).

Results

Number of Reaches

Figure 3 depicts the mean number of reaches during test. Preliminary analyses revealed no main effects or interactions of familiarization trial order, test trial order, gender, or test objects except for a higher order interaction between familiarization order, test trial order, set, and trial type that could not be interpreted. Therefore, all subsequent analyses collapsed across these variables.

To determine whether infants' frequency of reaching differed across outcome types, a 2 (trial set) × 3 (outcome type) ANOVA was conducted with both factors within-subjects. This analysis revealed only a main effect of outcome type, $F(2, 30) = 5.06$, $p < .02$. Infants reached differentially across the three outcome types (see Figure 3). Preplanned Helmert contrasts confirmed this pattern. Infants reached more often on two-object/unexpected outcomes than on the average of the two expected

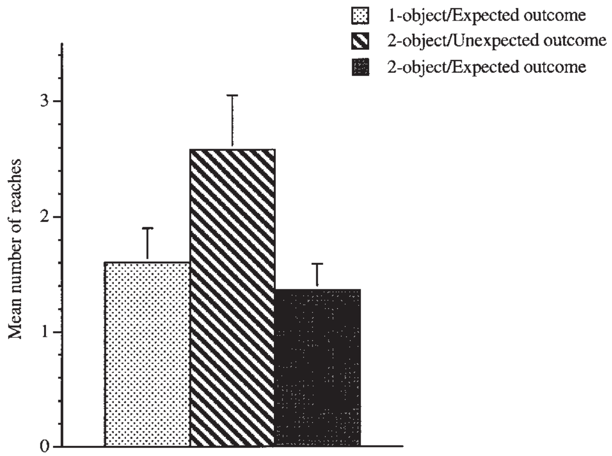

FIGURE 3 Mean number of reaches into box on one-object/expected, two-object/unexpected, and two-object/expected trials for infants in Experiment 2.

outcome types, $F(1, 15) = 6.15$, $p < .05$. The frequency of reaching to one-object/expected versus two-object/expected outcomes did not differ, $F(1, 15) < 1$, *ns*. Nonparametric analyses fully corroborated these findings. Ten of the 16 infants reached more often on two-object/unexpected than on one-object/expected outcomes (Wilcoxon $z = 2.21$, $p < .05$). Only 2 infants reached more often on two-object/expected than on two-object/unexpected outcomes (Wilcoxon $z = 2.20$, $p < .05$).

Search Duration

As in Experiment 1, the pattern of results for the searching time measure was virtually identical to the number-of-reaches measure. Therefore, we describe the results qualitatively only. Figure 4 depicts the mean duration of searching the empty box for each type of trial. Infants clearly differentiated the outcomes, searching longer when a second object should have been in the box (two-object/unexpected outcomes) than when the box should have been empty (one-object/expected and two-object/expected outcomes).

Discussion

The infants succeeded in Experiment 2. They reached more often and more persistently when they had retrieved only one of the two objects on two-object trials than when they had retrieved all the objects in the box (one object on one-object trials, both objects on two-object trials). The one-represented-object hypothesis cannot

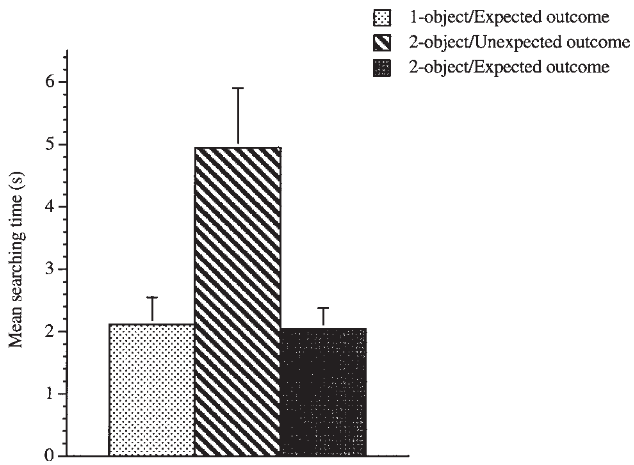

FIGURE 4 Mean duration of searching into box on one-object/expected, two-object/unexpected, and two-object/expected trials for infants in Experiment 2.

account for this result. Thus, Experiment 2 confirms that the violation of expectancy reaching method developed for this series of studies is sensitive to infants' representation of the precise number of objects in the box, at least in the cases of one and two objects.

A comparison of the 12-month-olds in Experiment 2 (Figures 3 and 4) with those in Experiment 1 (Figures 1a and 2a) suggests that the results of Experiment 2 are more robust than those of Experiment 1. If anything, the methodological changes introduced in Experiment 2 improved performance. This appearance is not borne out statistically; ANOVAs comparing the two studies revealed no main effects or interactions involving study. Nonetheless, in future studies using this methodology, we intend to follow the streamlined procedure of Experiment 2.

In the spatiotemporal condition of Experiment 1, *both* spatiotemporal and kind information specified two objects on two-object trials. For example, infants saw book and a telephone presented simultaneously. Experiment 2, in contrast, provided *only* spatiotemporal information; for example, infants saw two identical ducks presented simultaneously. Because of the methodological differences, any comparison between the two studies must be interpreted with caution. Still, no evidence in these data suggests that 12-month-old infants benefit from the presence of kind information in addition to spatiotemporal information; they did no better in the spatiotemporal condition of Experiment 1 than in Experiment 2.

GENERAL DISCUSSION

The development of this procedure had two goals. First, to provide a source of convergent evidence to the data from looking time methodologies, we sought a *manual search* method to explore the information infants use in support of object individuation. On the assumption that search is search for something, patterns of search provide relatively direct evidence concerning the number of objects the child represents inside the box. Second, we sought a measure that would place greater information-processing demands on infants than any used to date. On the assumption that production and recall is more difficult than recognition, the violation of expectancy manual search measure accomplishes this second goal.

Unlike looking time methods, the manual search paradigm provides no outcomes to which the child could react. Infants' representations of the objects in the box guide their search. Also, because infants are not presented with any visible outcomes, issues of baseline preference for one display or the other do not arise (a potential problem in the paradigm of Xu & Carey, 1996). For all these reasons, this procedure promises a new source of data to bear on the bases of object individuation and the representation of number in infancy.

The manual search paradigm presents infants with different task demands than any experiments to date that investigate the development of infants' ability to individuate objects. At no time during the test period in this study are infants presented with any visible information whatsoever to indicate how many objects are present in the box. Unlike previous looking time studies, infants cannot compare an outcome event or display with a stored image of the object(s) viewed previously. The manual search task is a recall rather than a recognition task. Success requires that infants produce a response in the absence of *any* concurrent visual information. Furthermore, on two-object trials, infants must hold the representation of the objects in mind for 10 sec to 20 sec (10 sec to play with the first object following retrieval plus 10 sec to try to retrieve the second object). Because it is a production task rather than a recognition task, and because it imposes greater demands on short-term memory, this task places higher demands on executive function than even the event-mapping (Aguiar & Baillargeon, 1997) tasks used by Xu and Carey (1996), in which infants are required to map a fully visible test display onto a representation of a previously seen occlusion event. Furthermore, this task requires that infants' representations of the objects they saw be robust enough to support a manual search rather than a looking response (see Munakata et al., 1997).

The across-the-board success of 12-month-olds, as well as that of 10-month-olds in the spatiotemporal condition of Experiment 1, establishes that this method can yield interpretable data at these ages, which are considerably younger than those tested in Starkey's (1992) related manual search procedure. In the studies reported here, infants showed by the persistence of their reaching that they distinguished when the box should have been empty, because all the objects hidden there had been removed, and when it should not have been. Success under these conditions reflects infants' ability to use the available information to construct a representation of one or two objects in the box and to use this representation to guide reaching. The differentiation of the different types of outcomes cannot be accounted for on the basis of differences such as the number of times an object emerged from the box, the number of times the experimenter's hands reached into the box, or the duration of the presentation. These factors were equated across one- and two-object trials and across the spatiotemporal and the property/kind alone conditions.

Despite these differences in task difficulty, however, results in this manual search paradigm converge precisely with those of Xu and Carey (1996) and Xu et al. (1999). Infants in all three sets of studies exhibit the same developmental shift between 10 and 12 months of age—success at 10 months exclusively when presented with spatiotemporal information regarding object individuation and success at 12 months on the basis of both spatiotemporal information and property/kind information. Of course, the simplified method of Experiment 2 in this research seemed to improve performance somewhat among older infants, raising the possibility that 10-month-old infants too might benefit from such modifications. Although this is an empirical possibility, we doubt it, on the grounds that the same 10- to 12-month shift recently has been obtained in a more dramatically simplified version of the search task (Uller, Leslie, & Carey, 2000). In this task, infants always see only one object placed into the box. On half the trials, the object retrieved is the object that was presented, and in half it is a new, different object. Searching into an empty box is then measured, as in these studies. If infants can use property or kind information to individuate objects, they should continue to search for the original object after they retrieve the new object but not after they retrieve the original object. Whereas 12-month-old infants succeeded at this task, 10-month-old infants did not.

This convergence of results over reaching and looking times is striking for two reasons. First, the manual search task presents different information-processing demands than looking time tasks. Second, manual search measures often reveal competence several months later than do looking time measures (Baillargeon & Graber, 1988; Baillargeon et al., 1990; Diamond, 1985, 1991; Hofstadter & Reznick, 1996; Hood et al., in press; Piaget, 1954). How are these results to be understood?

Converging patterns of development across widely different task demands and across looking and manual search paradigms suggest the presence of some change that is orthogonal to the development of general memory or executive function skills. One possibility is that the first representations of object kinds (or *specific sortals;* for discussion, see Carey & Xu, 1999; Macnamara, 1986; Xu, 1997; Xu & Carey, 1996) are constructed as infants approach their first birthday and that the information-processing difficulty of our tasks has the consequence that success depends on drawing on kind representations. This hypothesis requires that we distinguish between property representations and kind representations. It also requires independent evidence that kind representations are indeed being constructed during this age period. Finally, this hypothesis ideally should contribute to a resolution of the conflicts in the literature reviewed in the introduction—failure at using property/kind representations for object individuation until 12 months in the studies of Xu and Carey (1996, Xu et al., 1999) and in the studies reported here and success much earlier in the studies of Wilcox and Baillargeon (1998a, 1998b; Wilcox & Putthoff, 1998) and of Needham and her colleagues (Needham, 1998; Needham & Baillargeon, 1998). We take up these issues in turn.

1. *The distinction between kind representations and property representations.* Just as J. M. Mandler (1988, 1992, 2000) distinguished between perceptual and conceptual categorization, it is also likely that individuation takes place at many different levels of processing. Paradigm perceptual processes such as figure-ground segregation, for example, can be seen as an individuation problem, as can the object-tracking mechanisms of midlevel vision (e.g., Trick & Pylyshyn, 1993). Perceptual properties, such as color, texture, size, form, features of good gestalt, and spatiotemporal aspects of displays, may contribute to individuation

processes at a perceptual level, in different ways than kind concepts contribute to object individuation.[3]

Kind representations are conceptual representations. As Mandler drew the distinction, kinds provide the natural answers to “What is it?” whereas properties do not (compare “It’s a *telephone*” with “It’s *black*”). Kind representations differ from property representations along many dimensions. Kind concepts provide criteria for individuation and numerical identity, whereas property representations, on their own, do not (one can count the telephones in the room but not the black in the room). Kind concepts are stable, long-term representations that capture information about causally correlated features of objects. They have causal/functional properties at their core, and they fall in the domain of psychological essentialism. As a result, kind concepts support inductions about object properties and functions that are not directly perceptible. Finally, kinds are typically lexicalized as nouns, whereas properties are typically lexicalized as adjectives and other lexical types.

An important aspect of kind representations is that they provide summary symbols for categories and individuals that may be placed into working memory, that is, the objects on a stage, or in a box, may be represented directly as *a duck* and *a car*. The format of these symbols may be mentally represented lexical items, if the baby knows the word, or interpreted images (for a review of experiments in which lists of images are held in working memory, see Sternberg, 1975). What is important is not the format of the representation, but the existence of symbols that stand for kinds of objects.

2. *Evidence that kind representations are developing as infants approach their first birthday.* It is an open question when infants begin to represent true kind concepts. Furthermore, there is no reason to believe that full-blown kind representations first emerge in a narrow time window. Landau, Smith, and Jones (1988), for example, argued that the transition from concepts based on perceptual similarity to those based on deeper causal/functional properties begins during the third year of life and continues during the preschool years. Nonetheless, convergent evidence from many laboratories suggests that several reflections of kind representations first become evident in the age range of 9 to 12 months.

In a series of elegant studies, J. M. Mandler and her colleagues provided evidence that by 9 to 11 months of age, infants can form categories of objects that are not exclusively driven by perceptual similarity but rather seem to be conceptual in nature (for a review, see J. M. Mandler, 2000). For example,

[3]It is important to note that perceptual properties also can be represented conceptually, as in the explicit symbols lexicalized as adjectives in natural languages. The distinction we are drawing here is not between sortal concepts and property concepts, but between conceptual representations and perceptual representations. Although it is notoriously difficult to draw this distinction, we feel it unlikely that an adequate theory of cognitive architecture will be able to dispense with it.

11-month-old infants' categorization of animals, vehicles, kitchen utensils, plants, and furniture seems to be driven by global kind category membership rather than overall perceptual similarity (J. M. Mandler & McDonough, 1993, 1998). Moreover, when an unambiguous but kind-irrelevant property commonality—color similarity—is pitted against kind-relevant properties (animal/vehicle: shape, structure, and configuration of parts), 9-month-old infants overlook commonalities in color and respond to objects instead on the basis of their kind category membership (Van de Walle, 1999). Indeed, infants this age even appear to be capable of making simple inductions on the basis of membership in the category animal or vehicle, one of the hallmarks of conceptual representations of object kinds (McDonough & Mandler, 1998). Similarly, Baldwin, Markman, and Melartin (1993) demonstrated that the capacity to project a nonobvious functional property from one object to another of the same similarity emerges robustly between the ages of 9 and 11 to 12 months.

Furthermore, it appears that by 9 months of age, common labels support infants' analysis of kind category similarity (Balaban & Waxman, 1997; Waxman & Balaban, 1996), and contrasting labels support object individuation in Xu and Carey's paradigm (Xu, 1998). Furthermore, Waxman (1999) recently showed that by 13 months, infants have made an explicit linguistic distinction between kind concepts and property concepts, expecting nouns to refer to taxonomic kind categories and expecting adjectives to support categorization on the basis of similarity in properties like color or texture, as well. In these studies, infants handled a series of objects whose only commonality was a salient property (e.g., a red truck, a red dog, a red apple). For some infants, each object was labeled with a novel noun (e.g., "This one is a *blicket*"); for others, an adjective was applied (e.g., "This one is *blickish*"). Only in the adjective condition did infants categorize on the basis of the property similarity.

The distinction between kind representations and perceptual property representations raises the question of whether the 12-month-old infants' success in the kind alone condition of Experiment 1 was based on the kind differences or the property differences between the two objects. Although concepts lexicalized as properties do not by themselves provide criteria for individuation (one cannot count the red in a room, the big in a room, the striped in a room), under the conditions of Experiment 1, as well as in the studies by Xu and colleagues (Xu & Carey, 1996; Xu et al., 1999), perceptual property differences among the objects do provide relevant information about individuation. For example, if you see me draw a black plastic object from a box, return it, and then remove a red, striped, round, rubber object, you might infer that two objects are in the box, even if you did not identify the objects as a telephone and a ball. On the basis of currently available information, we cannot know for sure whether the 12-month-olds are individuating the objects on the basis of kind differences or on the basis of perceptual property differences, although current research is investigating this question.

A recently completed series of studies with 12-month-olds suggests that they, like 13-month-olds, distinguish property representations from kind representations and that kind representations underlie the success in Xu and Carey's (1996) paradigm and, by extension, perhaps this one as well (Xu & Quint, 1997). The procedure followed that of Xu and Carey, only the objects were, for the most part, objects of a single kind that differed in properties such as color, size, or shape. For instance, infants might see a pink cup emerging from the left of the screen, followed by an identical yellow cup emerging from the right, or they might see a big cup followed by a small cup, or a mug followed by a sippy cup. Infants were even tested with a pair that differed in many properties—a big, red, striped cup and a small, blue, solid-colored cup. During test, the screen was removed to reveal either two cups (expected on the basis of property information) or just one of the cups. Adults easily use these property differences to infer two distinct objects. However, the 12-month-olds failed to do so, succeeding only on cross-kind comparisons. In the cross-kind comparisons (a cup and a ball, a cup and a bottle), properties such as color, material, texture, and size were kept constant. To date, only kind differences (or kind-relevant shape differences) have been found to provide 12-month-old infants with criteria for individuation and numerical identity in this series of studies.

We also have carried out a first study on 12-month-olds' capacity to individuate objects on the basis of a property difference using the manual search paradigm. Using the simplified procedure of Uller et al. (2000), Feigenson and Carey (2000) examined whether size differences would support individuation at this age. Infants saw a single object (e.g., a car) removed from and returned to the box, which was then presented for reaching. On some trials, the infant retrieved the presented object. On other trials, the object retrieved was a much larger or a much smaller (two times the front surface area or four times the volume or half the surface area and one quarter the volume) but otherwise identical object. Infants failed to establish representations of two distinct objects on the basis of the dramatic difference in size, again failing to use a property difference as a basis for object individuation at 12 months.

These results bring into sharp relief one aspect of the conflicting literature on infant object individuation: Why do 10-month-olds in the studies of Xu and her colleagues and in these manual search studies, and even 12-month-olds in the series of studies just reviewed, fail to use properties for individuation, whereas much younger children succeed in doing so in the studies of Baillargeon, Needham, Wilcox, and their colleagues (for a review, see Needham & Baillargeon, 2000)?

3. *Does the distinction between kinds and perceptual properties help resolve the discrepancies in the literature concerning the age at which infants can use property/kind information to individuate objects?* As pinted out by Wilcox and Baillargeon (1998a) and by Needham and Baillargeon (2000), previous studies by Xu and Carey, and, we would argue, the studies reported here place greater information-processing demands on the child than do those of Wilcox and Baillargeon

(1998a, 1998b) or Needham (1998; Needham & Baillargeon, 1998). Information-processing demands cannot be the sole source of variance in infant success among these studies, for this study did not prove *more* difficult than the earlier Xu and Carey studies, despite the fact that the manual search task requires recall rather than recognition and requires that object representations be held in working memory for 10 sec to 20 sec on two-object trials. Still, it seems likely that variations in information-processing load contribute to the differences in ages at which infants succeed at these different tasks.

We suggest that the greater information-processing demands of the current task, and those of Xu and Carey (1996), preclude successful individuation at perceptual levels and make it necessary for the child to encode the objects in terms of kind concepts to succeed, such that acquisition of kind concepts becomes a limiting factor in the child's success in these studies (for an extended treatment of this suggestion, see Xu & Carey, 2000).

Consider the differences between Needham's (1998) individuation studies, on the one hand, and those of Xu et al. (1999), on the other. In a representative Needham study, 7-month-old infants used the property differences between a blue, rectangular box, and an adjacent yellow cylinder to parse an ambiguous display into two objects. They were shown the ambiguous stationary display for only a few seconds, that is, unlike infants in Xu et al.'s paradigm, they were not habituated to the ambiguous stationary display (which provides spatiotemporal evidence for a single object that must be overcome). Furthermore, property evidence for two objects in Needham's studies is extremely strong—every available configural property (color, size, form, texture, surface pattern, discontinuities in boundaries) indicates the same parsing of the display. Xu et al.'s objects were complex and multiparted—property differences in the duck/car array could have supported individuation of the eyes from the head, the head from the body, the body from the feet, the duck from the car, the windowed top of the car from the body, or the body from the wheels. Perhaps under conditions in which spatiotemporal evidence indicates one object and in which property information is highly ambiguous, infants must draw on kind information (*duck/car*) to succeed at the task.

Similarly, as Wilcox and Baillargeon (1998a, 1998b) pointed out, the multiple emergences and occlusions of the objects and substantial short-term memory demands of the studies reported here and those of Xu and Carey (1996) differentiate these studies from those in which infants apparently succeed at using property differences to individuate the objects. Perhaps under such demands, it is helpful, or even necessary, for the infant to possess a mental kind symbol that can be placed into short-term memory to support object individuation. This hypothesis is consistent with the findings concerning the role of language in success in these tasks: 10-month-olds who know labels for the objects succeed in Xu and Carey's original (1996) studies, and 9-month-olds succeed in the task if the objects are differentially labeled when removed from each side of the screen (Xu, 1998).

This analysis raises a number of immediate questions. First, what kind representations are known to 12-month-olds and which are being used in the current research? Second, must infants have antecedently constructed kind representations for such representations to support individuation? Finally, how do infants distinguish differences that signal likely kind contrasts and differences that do not? It seems likely to us that by the end of the 1st year of life, infants may have constructed kind representations for at least some of the familiar objects used in the current research (e.g., book, telephone). It also seems likely that infants can construct representations for novel object kinds, because presumably for infants many object kinds are novel. It is unclear how infants represented the novel objects (e.g., juicer, globe-with-feet) in these studies. They may have mistaken them for known kinds such as balls or hats, or they may have constructed new representations for them. Although ongoing studies in our laboratories are beginning to address these issues, at this point, answers to these questions must remain entirely speculative.

We offer the suggestion that the 10- to 12-month-old shift we see in our studies reflects the first emergence of the capacity to bring kind representations to bear on object individuation tentatively. Much further research is needed to disentangle the multiple levels at which object individuation takes place as well as the developmental time course and information drawn on in different processes. Such research is currently in progress. Here we offer a new method to bring data to bear on these problems and further evidence for one developmental change in human infants' bases for object individuation between the ages of 10 and 12 months.

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