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5

The Development of Object Individuation in Infancy

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William James (1890/1950) once described the infant's world as "a blooming, buzzing confusion"; Piaget (1954) and Quine (1960) both thought that the young infant's experiences of the world are fleeting and disjointed. According to these psychologists and philosophers, the infant's world is fundamentally different from adults' in the following way: There are no persisting objects. This claim has two parts: First, until about 8 or 9 months of age, infants do not have object permanence, a phenomenon that had been studied extensively by Piaget and his followers. Second, infants do not have any criteria for deciding whether an object seen on one occasion is the same as or distinct from an object seen on a different occasion, a characterization with far-reaching consequences, as argued most extensively by Quine (1960). Several decades later, with an ever-growing enterprise of the developmental psychology of infancy (Clifton, 2001), we now know that both of these claims are wrong.

Seminal work by Baillargeon, Spelke, and Wasserman (1985) showed, using a habituation–dishabituation paradigm pioneered by Fantz (1961, 1963, 1964) and further developed by Kellman and Spelke (1983) and Spelke (1985), that 5-month-old infants have object permanence. Since then, a wealth of evidence has shown that infants are highly sophisticated creatures capable of using a variety of perceptual cues for object segregation, separating figures from the background of a scene, and grouping surfaces into three-dimensional objects (see Johnson, 2000; Spelke, 1990, for reviews).

Once infants have segregated objects from the background, however, they face a further task: How do they keep track of these objects through space and time? Under what conditions do infants decide that they are in the presence of one, two, or three distinct objects? How do they decide whether the objects they have encountered on different occasions are the same objects seen at different times or distinct objects seen at different times? What criteria do infants employ in making such decisions? This problem has been dubbed *object individuation.*

This chapter is concerned with object individuation. I argue that human adults possess two systems for object individuation: an object-based individuation system and a kind-based individuation system. I review evidence suggesting that the object-based individuation system is in place early in infancy, whereas the kind-based system begins to develop toward the end of the first year of life. Last, I present evidence suggesting that the development of the kind-based individuation system may be driven by learning a natural language.

To probe which system of object individuation is present in infants, I present empirical findings on the types of information infants use to establish representations of objects in their environment. I discuss three types of information and their relation with each other: spatiotemporal information, perceptual property information, and object kind information.[1]

Adults use all three types of information in solving the problem of object individuation. Spatiotemporal information includes specification of location and paths. If an object is seen at some point today and an object is seen at some point tomorrow, adults arrive at a representation of two distinct objects if there is no spatiotemporally continuous path that could unite the two occurrences. Perceptual information includes dimensions such as color, texture, size, and shape. Adults conclude that a blue cup is a different object from a previously seen red cup because of the perceptual difference of color. Last, kind information specifies categorization under concepts such as *table, chair, dog, cat, car,* and *person,* categories of objects that are united by functional and causal features as well as by perceptual features. Adults draw on kind information in the service of object individuation when they conclude that the dog that went behind a tree cannot be the same individual as the cat that was found in the same location at a later time.

The object-based individuation system uses both spatiotemporal and perceptual property information, with the latter playing a decidedly secondary role. That is, spatiotemporal information overrides perceptual property information. The kind-based individuation system uses both kind and perceptual property information, with the latter playing a secondary

[1]The term *perceptual property information* refers to the same type of information as the term *featural information,* for example, shape, texture, size, color, and so on.

role. Perceptual property information is kind relative; that is, particular perceptual property differences indicate a new, distinct object only within certain kinds. For example, a green ball and a red ball seen at different times are two distinct objects, but a green leaf and a red leaf seen at different times may not be if it happens to be autumn and leaves are changing color.

TWO INDIVIDUATION SYSTEMS IN ADULTS: OBJECT-BASED SYSTEM AND KIND-BASED SYSTEM

Developmental psychologists are primarily interested in how a seemingly helpless and cognitively deficient baby grows into an adult who possesses a vast amount of knowledge and impressive cognitive skills. To achieve such an understanding, we need a specification of what the adult conceptual system is like, that is, the end-state of development. Equally important is that we also need a specification of what the young infant's conceptual system is like, that is, the starting-state of development. Once we have a clear picture of the starting-state and the end-state, we can then delve into the question of when and how the system develops along the way. Thus, I begin with a brief analysis of how object individuation is accomplished by adults.

Object-Based Individuation System in Adults

An object is a bounded, three-dimensional entity that moves as a whole (Spelke, 1990). An object-based system of individuation has the concept *object* at its core. At this level, spatiotemporal criteria are used: (a) An object cannot be at two places at the same time, (b) two objects cannot be at the same place at the same time, and (c) objects travel on spatiotemporally connected paths. If spatiotemporal discontinuity is detected, then two distinct objects are present; conversely, if a spatiotemporally connected path can be established between two occurrences of an object, then a single object is present. For example, if a person comes out of a forest and goes into a cabin, and a physically identical person comes out of the forest and goes into the same cabin, with no apparent continuous path uniting the two occurrences, then an adult would be forced to conclude that there are two distinct people and they happen to be identical twins. Such inferences are made on the basis of spatiotemporal evidence alone, because the two people are featurally identical. Spatiotemporal criteria are very general; they are true of any physical object regardless of the kind or category to which the object belongs.

Within the object-based individuation system, perceptual property information plays a much less important, secondary role. In the absence of strong spatiotemporal information, object properties, such as being red or being square, may enter into the computation for whether a second object is present. However, spatiotemporal information can easily override perceptual property information in this system. The paradigmatic case is apparent motion. Suppose an adult is shown a display consisting of a red circle on the left and a green triangle on the right and then is shown a display consisting of a green triangle on the left and a red circle on the right, both displaced from the original location. Under certain conditions (e.g., a certain range of interstimulus intervals between the two displays), the adult would perceive a red circle turning into a green triangle, and vice versa (Fig. 5.1), even though the perceptual property information specifies that the two objects have switched places. Even under conditions of occlusion, spatiotemporal information can override perceptual property information, as in the tunnel effect (Burke, 1952). For example, if a red circle goes behind an occluder (or disappears into a tunnel) and a green triangle comes out from the other side, given a certain range of speed and occlusion time, adults perceive a single object persisting through occlusion and changing its properties. Thus the visual system takes into account various spatiotemporal parameters and sometimes yields a representation of a single object persisting through occlusion despite perceptual property differences. In addition, as far as the object-based individuation system is concerned, all perceptual property differences are created equal. A green ball turning into a red ball has the same status as a green leaf turning into a red leaf, even though the latter is far more plausible (e.g., during the fall season) than the former.

Last, representations of object kind do not play a role in this system. If one replaces the red circle and the green triangle in Fig. 5.1 with a dog and a cat, the same percept remains; that is, under certain conditions an adult would perceive the dog turning into the cat, and vice versa. Strong spatiotemporal information can override object kind information just as it can override perceptual property information.

Kind-Based Individuation System in Adults

A second system of individuation, dubbed the *kind-based individuation system* in this chapter, is clearly present in adults. Instead of having the concept object at its core, object kind concepts—such as *dog*, *cat*, *table*, *chair*, *ball*, *cup*, *car*, and *person*—are at its core. What characteristics of this system distinguish it from the object-based system?

The kind-based individuation system is fully conceptual, drawing on kind information for decisions about individuation. Individuation is based on kind information when no relevant spatiotemporal evidence is available or if spatiotemporal evidence is misleading, as when an adult decides that the cup on the windowsill is the same cup she left there yesterday, but the cat on the windowsill is not the same object as the cup she left there yesterday, even though the two objects occupied the same location. Perceptual property information is relevant to individuation, but not on its own.

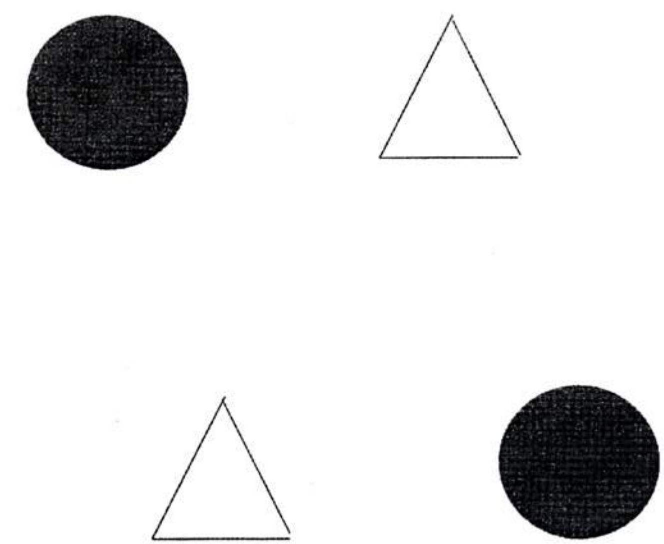

FIG. 5.1. Schematic representation of apparent motion.

Adults' inferences concerning the relevance of perceptual property differences are kind relative; in contrast to the object-based individuation system, not all perceptual property differences are created equal. A puppy may be the same creature as a large dog a month later, but a small cup cannot be the same object as a large cup a month later. Similarly, color differences do not signal distinct individual chameleons, but they do signal distinct individual frogs.

The two object individuation systems track objects differently, as shown in Fig. 5.2. Suppose you examine Panel 1 of this figure, then you lose perceptual contact with the scene, and then you return a few minutes later to view Panel 2. You would probably describe the two scenes as the rabbit having moved from above and to the left of the chair to below and to the right of it, while the bird having moved from the bottom left to the top right. In this scenario, individual objects are tracked by the kind-based system, using kind membership as the basis for its decision. Now imagine that a fixation point replaces the chair and that Panel 1 and 2 are projected one after another onto a computer screen while you maintain fixation. If the timing of the successive stimuli supports apparent motion then, rather than seeing a bird and a rabbit each moving diagonally, you would see two individuals each changing back and forth between a white, bird-shaped object and a black, rabbit-shaped object. The object-based individuation system is re-

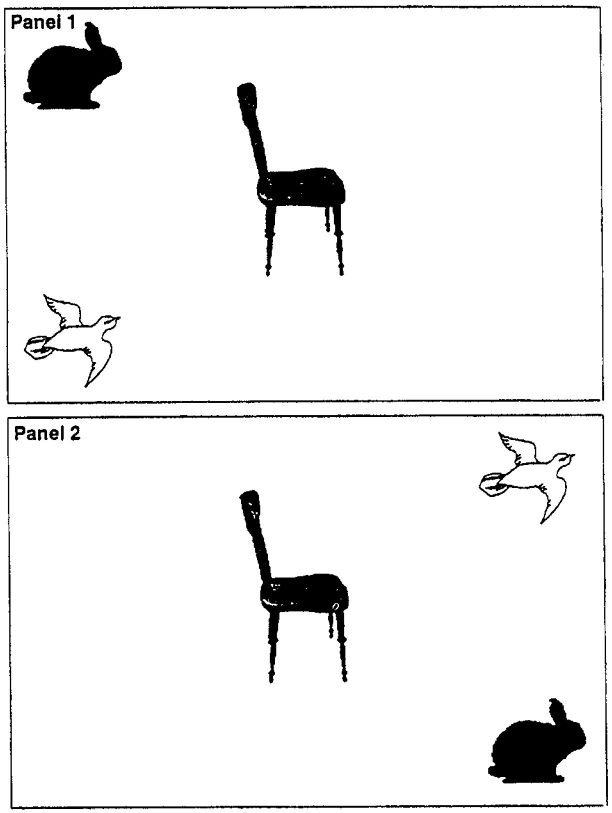

FIG. 5.2. Schematic representation of the two systems of object individuation.

sponsible for the second scenario, and it settles on a different solution than does the kind-based individuation system.

Similarly, a parallel case can be constructed with occlusion, as in the tunnel effect. Suppose you see a dog disappear behind an occluder, and a few minutes later a cat emerges from the other side. You would probably describe the scene as a dog going behind an occluder and staying there, followed by a cat (who was presumably behind the occluder to begin with) coming out from the other side. Now imagine viewing the whole sequence of events on a computer screen. If the timing supports the tunnel effect, then you would see an individual persisting through occlusion with dog properties at the beginning and cat properties at the end. Again, the kind-based system is responsible for the first scenario, in which individuation is based on kind membership, whereas the object-based system is responsible for the second scenario, in which individuation is based on spatiotemporal continuity. The two systems settle on different solutions as to how many individuals are present in the event.

WHEN DOES THE OBJECT-BASED INDIVIDUATION SYSTEM DEVELOP IN INFANTS?

Armed with an analysis of the end-state of the development of object individuation, I now turn full attention to how such systems develop in infants. Most of the infant studies reviewed in this chapter have used the violation-of-expectancy looking time methodology (Spelke, 1985). In these experiments, infants watch events unfold before them. After being familiarized with or habituated to the events, they are then shown, in alternation, an expected outcome (an outcome that is consistent with adults' understanding of the world) and an unexpected outcome (an outcome that is inconsistent with adults' understanding of the world, for example, a magic trick). If infants have the same understanding of the events as adults, then they should look longer at the unexpected outcome relative to the expected outcome.

This method is widely used in studies of infants of 2 months and older (Aguiar & Baillargeon, 1999), and it may yield interpretable findings in newborns (e.g., Slater, Johnson, Brown, & Badenoch, 1996 although, strictly speaking, Slater et al. (1996) used a habituation–recovery-to-novelty method). I now describe three studies from different laboratories that illustrate infants' use of spatiotemporal information in the service of object individuation.

Spelke, Kestenbaum, Simons, and Wein (1995; see also Spelke & Kestenbaum, 1986, and Moore, Borton, & Darby, 1978) asked if 4-month-old infants were able to use spatiotemporal discontinuity to determine how many objects were involved in an event. In the discontinuous-movement condition, they presented to the infants two screens with a gap in between (see Fig. 5.3). An object emerged from behind the left screen to the left side of the stage, and then returned behind the left screen. After a short delay, a physically identical object emerged from behind the right screen to the right side of the stage and then returned behind the right screen. No object ever appeared in the space between the two screens. Because an object cannot get from Point A to Point B without traversing a spatiotemporally continuous path, adults conclude that there must be two distinct objects involved in this event: one behind the left screen and one behind the right one. What about these young infants? Can they also use spatiotemporal discontinuity to establish a representation of two distinct objects? After the infants were habituated to the event in which the objects alternately emerged from behind the screens and returned behind them, the screens were removed on the test trials, revealing either two identical objects (the expected outcome) or just one object (the unexpected outcome). The infants looked reliably longer at the one-object, unexpected outcome, suggesting that they had established representations of two distinct objects in this event.

A possible alternative interpretation of this finding is that perhaps the infants expected to see two objects simply because there were two screens

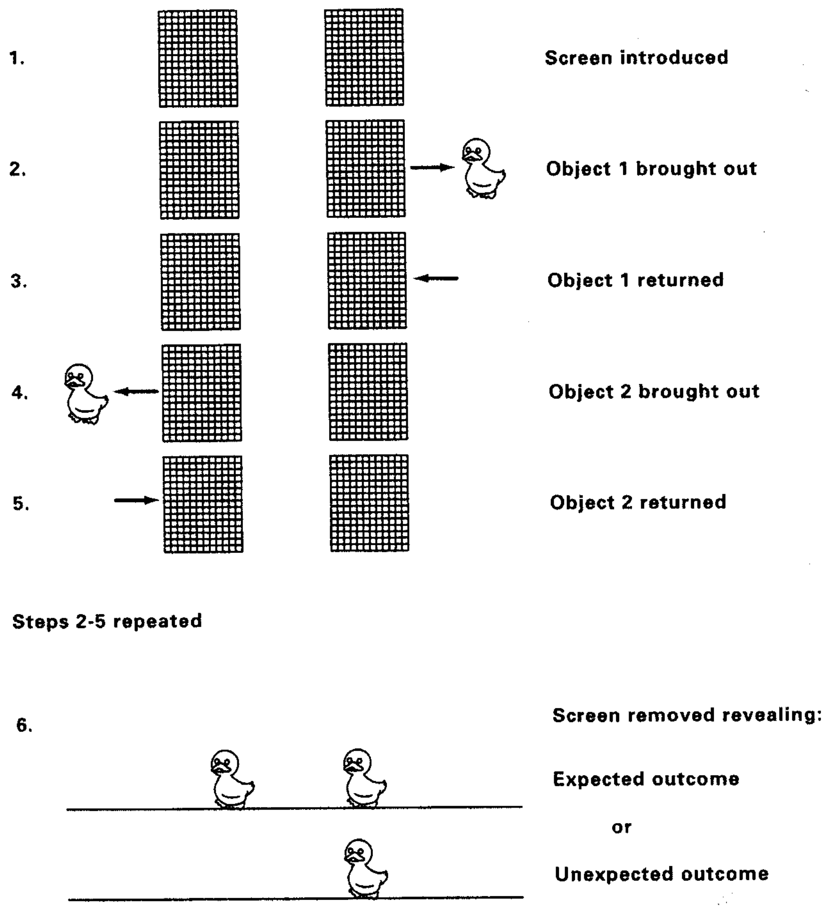

FIG. 5.3. Schematic representation of the experimental paradigm in Spelke et al. (1995).

on the stage. To rule out this alternative, Spelke et al. (1995) included a continuous movement condition in which the object did appear in the space between the two screens. The infants looked more equally at the one- and two-object outcomes, providing a different pattern of looking from the discontinuous condition. In other words, infants did analyze the path of motion of the objects, and they did not expect two objects just because there were two screens.[2]

[2]In this study, 4-month-old infants were agnostic as to how many objects were involved in the continuous-movement condition. In a replication with 10-month-olds, Xu and Carey (1996) found that infants established a representation of a single object in the continuous-movement condition; they looked reliably longer at the two-object outcome.

Building on these results, Baillargeon and Graber (1987; see Baillargeon, 1995, for a review) showed that 5.5-month-old infants can use the simultaneous presentation of two objects to guide their physical reasoning. If two tall rabbits were shown during familiarization, one standing to the left of the left screen and one standing to the right of the right screen, the infants did not look longer at the event in which there was apparent discontinuous movement (an event very similar to the one in Spelke et al., 1995). These results suggest that infants were sensitive to the generalization that one object cannot be at two places at the same time. If two rabbits were shown simultaneously, the infants established a representation of two distinct rabbits. If two distinct rabbits were present, it was not surprising to see one rabbit going behind the left screen, and a second rabbit appearing from behind the right screen without any rabbit appearing in the space in between the screens.

Using a different procedure, Wynn (1992) provided further evidence that infants are able to use spatiotemporal discontinuity for object individuation. Five-month-old infants watched a Mickey Mouse doll being placed on a puppet stage. The experimenter then occluded the doll by raising a screen. A second doll was then deposited behind the screen. Next, the screen was lowered, revealing either the expected outcome of two dolls or the unexpected outcome of one doll. Infants looked longer at the unexpected outcome than at the expected outcome. Because there was no obvious continuous path that could have united the first and the second Mickey Mouse dolls, the infants used the spatiotemporal discontinuity to arrive at a representation of two distinct objects.[3]

These results suggest that the object-based individuation system is present in infants as young as 4 months of age because they are able to use spatiotemporal information for establishing representations of objects and keeping track of them through space and time. What is the role of perceptual property information in this system for infants? Several recent studies have found that, under certain circumstances, infants are able to use perceptual property information for object individuation. However, this ability is very fragile, and spatiotemporal information can easily override perceptual property information. A more detailed discussion of this point will be presented in Section 5.[4]

[3]Wynn interpreted these studies as showing that infants understand that $1 + 1 = 2$. Irrespective of what these studies show about infants' representation of number, here I emphasize their implications for infant representations of objects.

[4]A number of researchers have recently identified the object-based individuation system with object-based attention in adults, including a variety of models, such as object files or FINSTs (e.g., Carey & Xu, 2001; Leslie, Xu, Tremoulet, & Scholl, 1998; Scholl & Leslie, 1999; Uller, Huntley-Fenner, Carey, & Klatt, 1999; and Xu, 1999, for discussions). Although several parallels exist between the results found with infants and those found with adults, the proposal that the two research communities have been studying the same mechanism is speculative.

WHEN DOES THE KIND-BASED INDIVIDUATION SYSTEM DEVELOP IN INFANTS?

Using the same violation-of-expectancy looking time methodology, my colleagues and I have found in several series of studies that the second, kind-based individuation system does not appear to be present in young infants but begins to develop at around 12 months of age (Xu & Carey, 1996; Xu, Carey, & Quint, 2001; Xu, Carey, & Welch, 1999; see Van de Walle, Carey, & Prevor, 2000; Wilcox & Baillargeon, 1998a, Experiments 1 & 2, and Bonatti, Frot, Zangl, & Mehler, in press, for replications; see Xu, 1997, and Xu, 1999, for reviews).

When Do Infants Begin to Use Object Kind Information for Object Individuation?

The studies described in the last section suggest that infants as young as 4 months of age draw on spatiotemporal information for object individuation, but they do not address the question of when the kind-based individuation system develops in infants. Imagine the following scenario: One screen is put on a puppet stage. A toy duck emerges from behind the screen and returns behind it. After a short pause, a ball emerges from behind the same screen to the other side and returns behind it (see Fig. 5.4). How many objects are behind the screen? For adults, the answer is clear: at least two, a duck and a ball. What type of information do adults use to arrive at this conclusion? Because there is only a single screen occluding the objects, and the objects are never seen simultaneously, there is no clear spatiotemporal evidence that there are two distinct objects. Instead, adults rely on their knowledge about object kinds to establish a representation of two objects. That is, adults know that ducks and balls are two different kinds of objects and that they do not typically turn into each other behind screens; thus, there must be two distinct objects. In one set of experiments, 10- and 12-month-old infants were shown the above-mentioned event (Xu & Carey, 1996). The objects contrasted at the superordinate as well as the basic level (e.g., a duck [animal] and a ball [artifact], or an elephant [animal] and a truck [vehicle]), or they contrasted just at the basic level (e.g., a cup and a bottle). Some objects were toy models (e.g., truck, duck), whereas others were highly familiar everyday objects (e.g., cup, bottle, ball, and book). Infants were either familiarized with or habituated to the event in which the two objects appeared from behind the screen one at a time. Then, on the test trials, the screen was removed to reveal either the expected outcome of two objects or the unexpected outcome of only one object. If infants are able to use object kind information for object individuation, then they should look longer at the unexpected outcome. The results, however, were surprising: Ten-month-old infants did not look longer at the unexpected outcome of one object. Their looking time pattern for the one- and two-object outcomes was not different from their baseline preference, which was measured by showing infants just the two outcomes without familiarization and, not surprisingly, the infants looked longer at two objects than at one object. In contrast, 12-month-old infants looked longer at the one-object, unexpected outcome, overcoming their baseline preference for two objects. In other words, 10-month-old infants failed to draw the inference that there should be two distinct objects behind the screen, whereas 12-month-old infants succeeded in doing so.

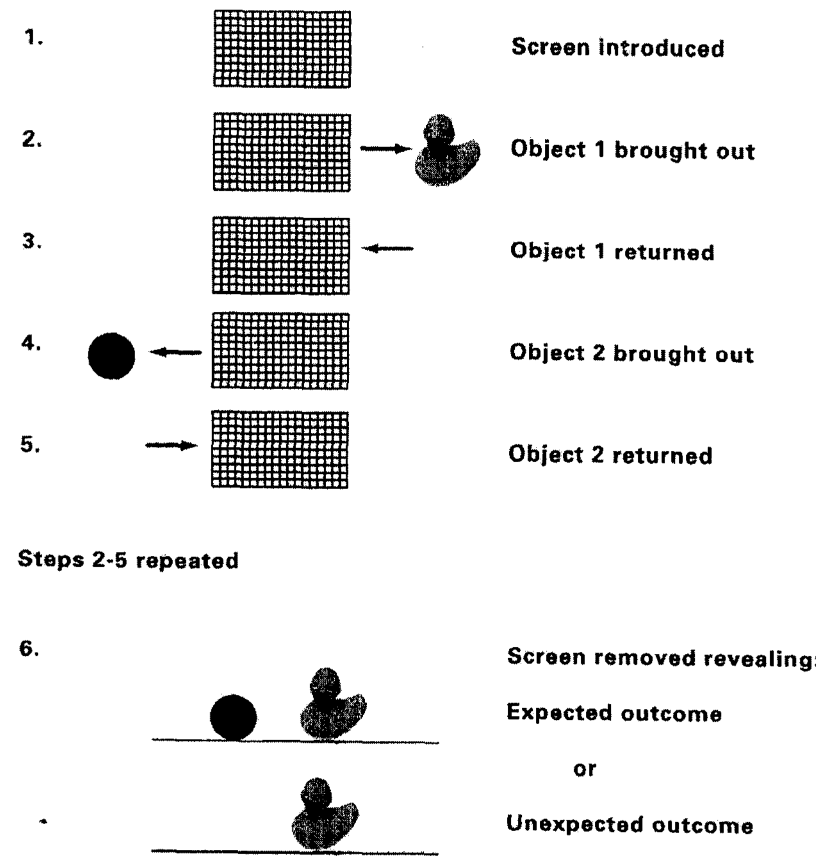

FIG. 5.4. Schematic representation of the experimental paradigm in Xu and Carey (1996).

Two critical control conditions established that the method was sensitive. When 10-month-old infants were shown the two objects *simultaneously* for 2 or 3 sec at the beginning of the experiment (see Fig. 5.5), they looked longer at the unexpected, one-object outcome, overcoming a baseline preference for two objects. Thus, when clear spatiotemporal evidence was provided, these infants were able to establish a representation of two distinct objects behind the screen.

Furthermore, Xu and Carey (1996) showed that the 10-month-old infants in their experiments were not blind to the perceptual differences between the two objects. During familiarization, one group of infants was shown the two objects alternating—for example, duck, ball, duck, ball—and their looking times on these four trials were recorded. A second group of infants was shown one object repeatedly—for example, duck, duck, duck, duck—and their looking times were recorded. The results showed that the looking times declined less for the first group of infants compared with the second group; that is, it took the first group of infants longer to habituate than the

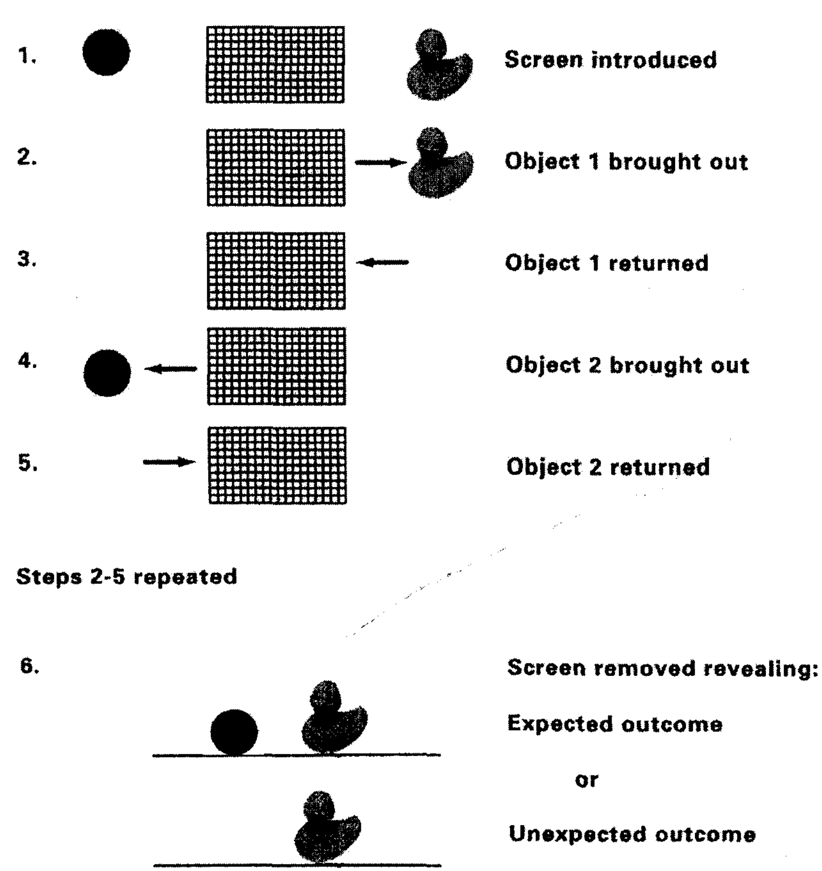

FIG. 5.5. Schematic representation of the spatiotemporal control condition in Xu & Carey (1996).

second group, presumably because the first group encoded the perceptual property differences between the two objects. This was an important control condition, because it replicated the results of infant categorization studies in which 3- or 4-month-old infants were shown to be able to distinguish dogs from cats (e.g., Eimas & Quinn, 1994). These results also allowed us to better characterize the failure of the 10-month-old infants: Their difficulty did not lie in not being able to encode the perceptual property differences between the objects; instead, their failure was due to not being able to take these perceptual property differences into account when computing how many objects were involved in an event.

These findings have been replicated in other laboratories. Wilcox and Baillargeon (1998a, Experiments 1 and 2) found the same developmental change using a modified looking time procedure. Infants were randomly assigned to one of two conditions: the box–ball condition or the ball–ball condition. In the box–ball condition, infants saw a box going behind an occluder and a ball emerging from the other side. The screen was then lowered to reveal a single ball on the stage. In the ball–ball condition, infants saw a ball going behind an occluder and the same ball emerging from the other side. The screen was then lowered to reveal a single ball on the stage. This event was repeated a few times. Infants at 11.5 months of age, but not infants at 9.5 months of age, looked longer at the single-ball outcome in the box–ball condition than in the ball–ball condition. Wilcox and Baillargeon (1998a) suggested that the older infants had used the perceptual property or kind information to establish a representation of two objects; therefore, they found the single-ball outcome unexpected in the box–ball condition. The younger infants, on the other hand, did not use the perceptual differences between the box and the ball to establish a representation of two objects; therefore, they did not find the single ball outcome unexpected.

A third line of convergent evidence comes from a study conducted by Van de Walle et al. (2000), who used a manual search procedure instead of the violation-of-expectancy looking time procedure. Ten- and 12-month-old infants were trained to reach through a Spandex slit into a box to retrieve objects; the box was constructed such that the infants could not see what was inside. Two types of trials were included: one-object and two-object trials in which individuation must be based on kind contrasts. In a one-object trial, the experimenter pulled out an object (e.g., a toy telephone) and replaced it into the box. This was repeated once. In a two-object trial, the experimenter pulled out an object (e.g., a toy telephone) and replaced it into the box; then the experimenter pulled out a second object (e.g., a toy car) and replaced it into the box. The box was then pushed into the infant's reach, and patterns of search were measured. After the infant had retrieved one object from the box, the experimenter surreptitiously removed the second object through a back flap of the box on the two-object trial. Thus, the box was empty on both the one- and two-object trials. The first object was taken away from the infant; therefore, she was expected to reach into the box again on both types of trials. The question was: How persistently would the infant search in the box on the one- and two-object trials when she found the box empty? If the infant has established a representation of two objects based on the kind contrasts (e.g., a telephone and a car), then she should search more persistently on the two-object trials than on the one-object trials. Twelve-month-old infants, but not 10-month-old infants, showed this pattern of results.

In a control condition in which spatiotemporal evidence was provided by presenting both objects simultaneously during familiarization, 10-month-old infants also searched more persistently on the two-object trials than on the one-object trials. These findings are completely consistent with those of the looking time studies of Xu and Carey (1996) and Wilcox and Baillargeon (1998a, Experiments 1 and 2).

Two conclusions can be drawn from these studies. First, these studies show that infants younger than 12 months of age rely almost exclusively on spatiotemporal information for object individuation. Second, these findings suggest that the second, kind-based system of individuation emerges at around 12 months of age.

Did 12-Month-Old Infants Use Perceptual Property or Object Kind Information When They Succeeded in Xu and Carey's (1996) Object Individuation Task?

In the studies described earlier, 10-month-old infants failed to draw on kind contrasts (e.g., duck [animal] vs. truck [vehicle]), for object individuation. They also failed to draw on perceptual property contrasts—for example, the contrast between being yellow, curvilinear, and rubber versus being red, rectilinear, and metal—for object individuation. When 12-month-old infants succeeded on the task, it was ambiguous whether their success was based on kind or perceptual property contrasts. My colleagues and I recently completed a series of experiments with 12-month-olds to address this issue (Xu et al., 2001). We asked if infants would also succeed on the task when property contrasts alone (e.g., color or size differences) were provided.

Using Xu and Carey's (1996) paradigm, we showed infants an event in which an object (e.g., a red ball) emerged from behind a screen and returned behind it, followed by an object (e.g., a green ball of the same size and material) that emerged from behind the other side of the screen and returned. On the test trials, the screen was removed. Infants were shown two objects (a red ball and a green ball—the expected outcome) or just a single object (a red ball or a green ball—the unexpected outcome) and looking times were recorded. We found that 12-month-old infants did not look longer at the unexpected, one-object outcome, suggesting that they did not use the color differences to establish a representation of two distinct objects.

Two control conditions were included to ensure that our method was sensitive. To ensure that the infants encoded the color differences, we compared a group of infants who saw the two objects alternating (e.g., red ball, green ball, red ball, green ball, etc.) with another group of infants who saw the same object over and over again (e.g., red ball, red ball, red ball, etc.). We found that it took the first group longer to habituate, thus providing evidence that infants at this age were able to encode the color differences in our experiment. In addition, we tested yet another group of infants for whom spatiotemporal evidence of two objects was provided, that is, the two objects—the red ball and the green ball—were shown simultaneously. In this case, the infants did look longer at the unexpected, one-object outcome on the test trials.

In two other experiments, infants were shown perceptual property differences involving size alone (e.g., a small red ball and a large red ball) or a combination of size and color (e.g., a small red ball and a large green ball), and they failed to establish two distinct objects based on these contrasts, just as in the color experiment. Again, control conditions revealed that the infants encoded the perceptual property contrasts, but they did not use them for the purpose of object individuation.

In the last experiment of this series, infants were shown two types of shape contrasts (with color, size, and surface pattern of the objects held constant)—a within-kind shape contrast (e.g., a sippy cup with two handles and a top vs. a regular cup with one handle) or a cross-kind shape contrast (e.g., a regular cup and a bottle). During familiarization trials, we found that the infants were equally sensitive to both types of shape contrast; that is, the rate of habituation was the same in the two conditions. On the test trials, the screen was removed to reveal one or two objects. Only the infants who saw the cross-kind shape contrast looked longer at the unexpected, one-object outcome; the infants who saw the cross-kind shape contrast did not look longer at the unexpected, one-object outcome. Together with the results of the first three experiments, in which property contrasts alone were provided, these findings provide evidence that kind representations (and not just perceptual property representations) underlie the success at 12 months.

In sum, Xu et al.'s (2001) studies support the claim that kind representations are distinct from perceptual property representations, as they play distinct roles in object individuation at 12 months. These studies also lend support to the conceptual distinction between object-based individuation and kind-based individuation, for this latter system emerges markedly later in development (see p. 185).

Object Individuation Studies and Infant Categorization Studies

Xu and Carey's (1996) results, and the replications just described, seem to contradict the findings of many infant categorization studies (Cohen & Younger, 1983; Eimas & Quinn, 1994; Quinn, Eimas, & Rosenkrantz, 1993). The following paradigm was often used in infant categorization studies: Three- and 4-month-old infants were familiarized with different pairs of exemplars from a given category—for example, cat—and then they were shown a pair of pictures consisting of a new exemplar from the old category (another cat) and an exemplar from a different category (e.g., a dog). The results showed that infants preferentially looked more at the picture with the exemplar from the new category, suggesting that they had extracted the category similarity during familiarization. These results were sometimes interpreted as evidence that infants represent basic-level kind concepts (e.g., Macnamara, 1986). Xu and Carey's (1996) findings, however, suggest that perhaps these infant categorization studies show early sensitivity to cat shape (or cat properties) and dog shape (or dog properties). The infants in the categorization studies did not encode the habituation stimuli as a series of distinct individuals (e.g., a cat, another cat, a third cat that is distinct from the first two) and then dishabituate to an object that is distinct from the cats (e.g., a dog). Instead, infants may have extracted the commonalities among the habituation stimuli as cat shape or cat properties and dishabituated to dog shape or dog properties. It is only when infants represent distinct individuals, such as cats and dogs, that warrants concluding that they represent kind concepts.

In my view, there was no contradiction *per se* between the infant categorization studies and Xu & Carey's (1996) results. The suggestion here (see also Xu, 1997; Xu & Carey, 1996) is that the categories revealed by many of the infant categorization studies are perceptual categories. To address the issue of kind representations (which are conceptual by definition), more stringent tests may be needed, e.g., object individuation tasks.

OTHER EVIDENCE CORROBORATING THE DEVELOPMENT OF KIND REPRESENTATIONS TOWARD THE END OF THE FIRST YEAR

Two other lines of research provide further evidence that kind representations begin to play an important role in the infant's conceptual system during the last few months of the first year of life.

In a series of experiments on object segregation, Xu et al. (1999) found the same 10–12 months shift as Xu and Carey (1996), Van de Walle et al. (2000), and Wilcox and Baillargeon (1998a, Experiments 1 and 2). Instead of the object individuation task in which infants were shown the objects one at a time, the objects in these experiments were in full view (see Fig. 5.6). Infants were habituated to a display consisting of a toy duck perched on top of a toy car, or a cup sitting on top of a baby shoe. In the test trials, a hand lifted up the top object, and the bottom object either stayed on the stage floor (the expected outcome if the infants had parsed the display into two distinct objects using kind information) or moved with the top object (as if they were a single object; this was the unexpected outcome). Twelve-month-old infants looked longer at the unexpected outcome, suggesting that they had used the kind distinction between a duck and a car (or a cup and a shoe) to segregate the display into two distinct objects, whereas 10-month-old infants failed to do so. Because the objects used in these experiments were complex (multicolored, consisting of multiple parts, and irregularly shaped), simple Gestalt principles would not have given a unique solution producing the correct, adult parse. Instead, Xu et al. (1999) argued that object kind representations (i.e., recognizing the display as consisting of a duck and a car, or a cup and a shoe) were required to succeed on this task.

In a categorization task, Waxman and Markow (1995) and Waxman (1999) showed that by 12–13 months infants are sensitive to the distinction between property and kind, as is marked by the linguistic distinction between count nouns (e.g., a *dog*, a *spoon*) and adjectives (e.g., it is *red*, it is *square*). In these studies, infants were shown a set of objects with which to play, one at a time. On hearing each of the objects being described by a count noun ("Look, it's a blicket"), infants showed a preference to play with an object of a different kind on the test trial, suggesting that they had extracted kind similarity during familiarization. In contrast, on hearing each of the objects being described by an adjective ("Look, it's a blickish one"), infants showed a preference for an object that differed in some perceptual property (e.g., color or texture) on the test trial, suggesting that they had extracted perceptual property similarity during familiarization.

THE ROLE OF PERCEPTUAL PROPERTY INFORMATION: A RESOLUTION FOR CONFLICTING DATA

So far I have argued that the object-based individuation system develops early in infancy and that it relies almost entirely on spatiotemporal information for establishing representations of objects. In contrast, the kind-based individuation system begins to develop at around 12 months of age, and it draws on representations of kinds in the service of object individuation. However, recent studies have investigated more closely whether perceptual property information or perhaps kind information plays a role in object individuation earlier than 12 months, and these new results have generated a lively debate in the field of infant cognition (Needham &

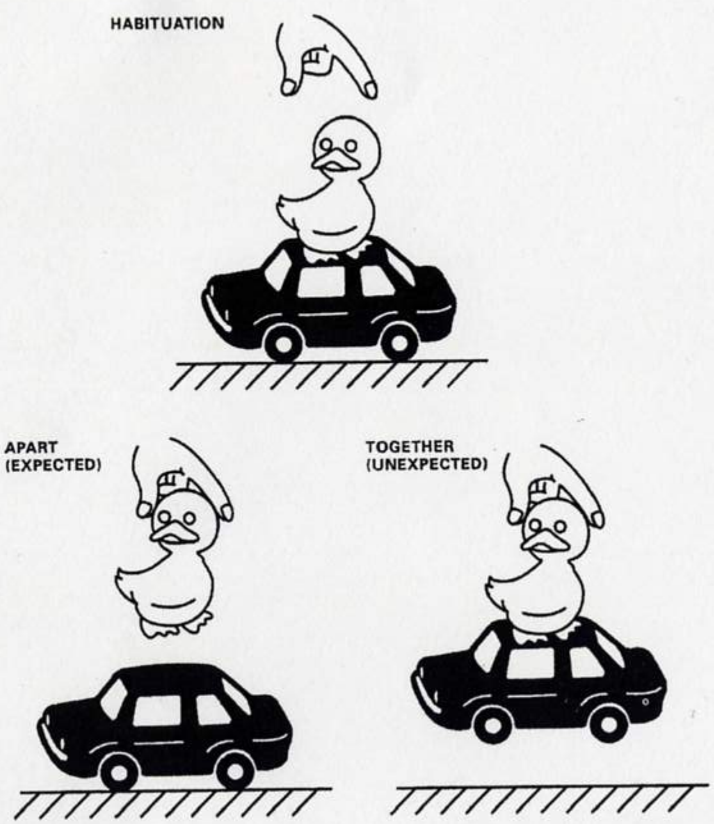

FIG. 5.6. Schematic representation of the experimental paradigm in Xu et al. (1999).

Baillargeon, 2000; Wilcox, 1999; Wilcox & Baillargeon, 1998a, 1998b; Xu & Carey, 2000; Xu et al., 1999).

In this section, I review the new experimental findings, and I attempt to provide a resolution for these conflicting data. First, I review a set of experiments, "narrow–wide screen" experiments, and provide a possible alternative account of these data. Then I review a second set of experiments, the "single-trajectory" experiments, and provide an analysis of why reducing the information processing demands resulted in earlier success. A prediction was made on the basis of this analysis, and it was borne out by a new study. I then analyze the differences across studies in terms of the types of information used for object individuation, and I review existing findings that provide additional support for this analysis. Last, I discuss two questions: (a) whether the basis of success in these new experiments was perceptual property information or kind information and (b) what these new results tell us about the characteristics and development of the two systems of object individuation.

The Narrow/Wide Screen Experiments and a Possible Alternative Interpretation

Wilcox and Baillargeon (1998b) conducted a series of experiments with 4.5-month-old infants, and their results suggest that perhaps even these young infants were able to use perceptual property–featural information if the experimental task was modified. In these studies, infants were shown a continuous event in which a red ball disappeared behind a screen and a blue box appeared from the other side, followed by a reversal in which the box disappeared behind the screen and the ball appeared from the other side. This event was presented continuously as long as the infants kept their attention on the stage area, and the screen was never removed to reveal one or two objects. Two conditions were contrasted: (a) a narrow-screen condition, in which the screen was too narrow to fit both objects behind side by side, and (b) a wide-screen condition, in which the screen was wide enough to fit both objects simultaneously. The hypothesis was that if the infants used the perceptual property differences between the ball and the box to arrive at two distinct objects, they would look longer at the narrow-screen event than at the wide-screen event, because the two objects could not fit simultaneously behind the narrow-screen. This result was obtained. Wilcox and Baillargeon (1998b) interpreted these findings as evidence that even 4.5-month-old infants are able to use property differences for object individuation.

Using the same methodology, Wilcox (1999) tested infants on displays in which the objects differed only in a single perceptual property (e.g., size or color). She found the following developmental progression: At 4.5 months, infants looked longer at the narrow-screen event when shape or size alone changed, but they did not look longer when surface pattern or color alone changed. At 7.5 months, infants looked longer at the surface pattern change, not until 11.5 months did the infants look longer at the color change. Wilcox interpreted these results as evidence that infants at various ages are able to use differences in perceptual properties for object individuation.

Inspired by the literature on the tunnel effect (Burke, 1952), Xu et al. (2001) raised a possible alternative account for the results just described. The key idea is that perhaps the narrow-screen event provided unambiguous and strong spatiotemporal evidence for a single object, leading the infant to interpret the event as a box turning into a ball. In contrast, the wide screen did not provide unambiguous spatiotemporal evidence for a single object, and the infant's percept was indeterminate as to how many objects there were. According to this alternative account, the longer looking for the narrow-screen event was due to the infants' finding the perceptual property changes interesting or anomalous. After all, infants do not generally see objects with box properties turning into objects with ball properties.

This alternative account is supported by psychophysical data from adults. Xu et al. (2001) presented adults with the same displays as the ones Wilcox and Baillargeon (1998b) used, and asked them a series of questions. Two findings are of particular interest here. First, when the narrow-screen event was presented to adults, 60% of them did not notice anything impossible about the event. It would be difficult to believe that 4.5-month-old infants would be better than adults at detecting that the combined width of the two objects was larger than the width of the screen. Second, and more important, when adults did detect some anomaly in the event, they all described it in terms of an object changing properties (e.g., "it went in a box and came out a ball"), as predicted by the literature on the tunnel effect (see Xu et al., 2001, for details of the data).

This alternative interpretation accounts for the available data. The reason why the 4.5-month-old infants looked longer at the narrow-screen event in Wilcox and Baillargeon's (1998b) study was because they found it interesting or anomalous that the objects changed their properties during occlusion. The developmental progression Wilcox (1999) found reflected the saliency of these different property changes. At 4.5 months, shape or size change (e.g., a small ball turning into a big ball) was more interesting than surface pattern change or color change; at 7.5 months, surface pattern change remained more interesting than color change; by 11.5 months, color change became sufficiently interesting to elicit longer looking. It is critical that the longer looking in these experiments reflected which property changes were salient and interesting to the infants, but it does not bear on the question of whether infants established a representation of two distinct objects behind the occluder using perceptual property differences. To show that infants did establish a representation of two distinct objects, an experimental paradigm is needed in which the outcomes (i.e., one or two objects when the occluder has been removed) are presented to the infants directly.

The Single-Trajectory Experiments and an Analysis of the Conflicting Results

Although the tunnel effect interpretation of the narrow–wide screen experiments is plausible, it is not viable for a second set of studies, the single-trajectory experiments (Wilcox & Baillargeon, 1998a, Experiment 8). Wilcox and Baillargeon (1998a, Experiment 8) used a much simpler procedure than that of Xu and Carey (1996). In the box–ball condition, 9.5-month-old infants were shown a box moving from one side of a stage and disappearing behind a screen, followed by a ball emerging from the other side of the screen. On the test trials, the screen was lowered to reveal only the ball. In the ball–ball condition, a ball moved behind a screen, and the same ball came out the other side. On the test trials, the screen was lowered to reveal only the ball. Infants looked longer at the single-ball outcome in the box–ball condition than in the ball–ball condition. Wilcox and Baillargeon (1998a) concluded that the infants must have used perceptual property or kind information to establish two distinct objects so that the single-ball outcome was unexpected in the box–ball condition.

How can one reconcile these results with those of Xu and Carey (1996) and Van de Walle et al. (2000)? There are at least two possible resolutions of these conflicting data. First, in the experiments conducted by Xu and Carey (1996) and Van de Walle et al. (2000), more complex objects were used (functional objects consisting of multiple parts) as opposed to simple geometric figures (Wilcox & Baillargeon, 1998a), and more complicated experimental procedures were used (multiple reversals of trajectory as opposed to a single trajectory), and thus higher information-processing demands were imposed on the infants. It may be that when information-processing demands are reduced, infants can show their ability to use perceptual property or kind information for object individuation at an earlier age. This is clearly part of the story. Second, and this is not inconsistent with the first possible account, when the information-processing demands of the task are high, the infants may have to draw on kind representations to succeed, whereas under certain circumstances, perceptual property representations suffice. According to this view, the relatively late success observed in Xu and Carey's (1996) and Van de Walle et al.'s (2000) studies may reflect the emergence of kind representations whereas the basis of the relatively early success observed in Wilcox and Baillargeon's (1998a) study may reflect the use of perceptual property representations.

Why should the higher information-processing demands of Xu and Carey's (1996) and Van de Walle et al.'s (2000) studies require kind representations in order to succeed on these tasks? What aspects of the tasks make such analysis plausible? Can empirical predictions be derived from this analysis?

The studies under consideration (Van de Walle et al., 2000; Wilcox & Baillargeon, 1998a; Xu & Carey, 1996) vary along several dimensions, at least three of which are potentially important. First, some studies used the violation-of-expectancy looking time methodology, whereas others used a manual-search methodology. Second, some studies used very simple geometric shapes (e.g., box/cube, ball/sphere), whereas others used more complex, functional, and nameable objects (e.g., cup, bottle, duck, and car). Third, the complexity of the procedures varied, both in terms of how many objects were shown during familiarization (a single object vs. two objects alternating) and how many repetitions were presented (single trajectory with no reversal of the object vs. multiple reversals of the object along its path of motion). Which of these factors affected performance? The difference in methodology is unlikely to be responsible for the earlier success of Wilcox and Baillargeon (1998a), because Van de Walle et al. (who used a manual search measure) found the same developmental shift as Xu and Carey (1996, who used a violation-of-expectancy looking time measure). The complexity of the objects may not be critical either, because a recent study by Bonatti et al. (in press) replicated the failure at 10 months using simple objects (e.g., box and cylinder) and the procedure used by Xu and Carey (1996). Therefore, one is left with the third factor: the complexity of the procedure. Wilcox and Baillargeon (1998a, Experiment 8) showed the infants a single object during familiarization, with no reversal of the object along its path of motion. In contrast, both Xu and Carey (1996) and Van de Walle et al. (2000) showed the infants two objects alternating during familiarization, with multiple reversals of the objects along their paths of motion. Perhaps this difference is responsible for the relatively late success observed in these two studies. If this analysis is correct, then one would predict that a simplified manual search task (in which only one object is shown during familiarization and the number of reversals is reduced) may lead to earlier success.

Xu and Baker (2001) tested this prediction with 10-month-old infants, using a procedure developed by Uller, Carey, and Leslie (2000). The basic design was the same as that of Van de Walle et al. (2000), with a few important changes. During the familiarization phase of the experiment, 10-month-old infants were shown a single object (e.g., a toy car) being pulled out of a box twice. The test trials were of two types. In a no-switch trial, infants retrieved the same object (the toy car) from the box, and then the object was taken away and the subsequent reach was recorded. In a switch trial, infants retrieved a different object from the one that had been shown (e.g., a toy duck), and then the object was taken away and the subsequent reach was recorded. As in Van de Walle et al.'s (2000) experiment, the experimenter had surreptitiously removed the other object (the toy car), so the box was in fact empty. If the infants can use the differences between a toy car and a toy duck to conclude that two distinct objects were inside the box, they should search more persistently on the switch trials compared with the no-switch trials. This prediction was borne out: Ten-month-old infants searched more persistently when they had retrieved an object that was different from the original object than when they had retrieved the original object. These new results provide evidence that the complexity of the procedure was likely responsible for the different ages at which success was found across the different studies.

A Conflict Between Perceptual Property Information and Spatiotemporal Information?

In the last section, I analyzed differences across studies in terms of the procedures, the complexities of the objects, and the use of different methodologies. A prediction based on this analysis was borne out by the empirical data. In this section, I attempt to analyze these differences in terms of the various types of information recruited for object individuation and return to the hypothesis that higher information-processing demands may require the infants to draw on kind representations. I then consider other existing data that are consistent with the analysis.

I suggest that the tasks used by Xu and Carey (1996) and by Van de Walle et al. (2000) present the infants with a conflict between perceptual property information (specifying two distinct objects) and spatiotemporal information (specifying a single object), and the experimental procedures provide stronger spatiotemporal evidence than those of Wilcox and Baillargeon (1998a) and Xu and Baker (2001). The stronger spatiotemporal information overrides the conflicting perceptual property information, leading the infants to establish a representation of a single object. Kind representations, when they become available at around 12 months of age, can override the strong spatiotemporal information, allowing the infants to establish representations of two distinct objects in these tasks.

Consider the studies conducted by Xu and Carey (1996) and Wilcox and Baillargeon (1998a, Experiment 8). Wilcox and Baillargeon (1998a) showed that a single trajectory with no reversals (i.e., if each object was shown only once, and neither object reversed its trajectory) made the task easier, such that 9.5-month-old infants succeeded in using the difference between a box and a ball to establish representations of two distinct objects. This ability, however, was very fragile. If one of the two objects came from behind the screen and reversed its trajectory once (Wilcox & Baillargeon, 1998a, Experiment 7), then 9.5-month-old infants failed at the task. If each object came from behind the screen and reversed its trajectory, and the whole event was repeated a number of times, as in Xu and Carey's (1996) experiment, even 10-month-old infants failed at the task. Why should this be so? The hypothesis is that the multiple emergences, back and forth on a single oscillating trajectory, may have provided stronger spatiotemporal evidence for a single object, as in the tunnel effect or in apparent motion. That is, if the infant's individuation system concludes that there were two distinct objects based on the perceptual property information and that there was only a single object based on the spatiotemporal information, then the back-and-forth oscillating trajectory persuaded the system that there was only a single object. As far as the infant's individuation system was concerned, spatiotemporal information overrides perceptual property information. Under these circumstances, kind representations may be needed to counteract such strong spatiotemporal evidence for a single object. Furthermore, multiple emergences placed higher demands on short-term memory. Infants must keep track of each emergence as to whether they have seen the object before. The availability of kind representations in the format for symbols, duck and car, is likely to facilitate this process, because these symbols act as "summary representations" that can be directly placed into short-term memory (Wilcox & Baillargeon, 1998a).

The manual-search studies conducted by Van de Walle et al. (2000) and Xu and Baker (2001) are subject to the same analysis. In Van de Walle et al.'s study, the fact that both objects came from the same location and were presented alternately (e.g., duck, car, duck, car) may have provided strong spatiotemporal evidence that a single object sometimes had duck properties and sometimes had car properties. In Xu and Baker's study, however, only one object was seen during familiarization, thus providing no evidence for an object with changing properties. Ten-month-old infants succeeded in the latter study, whereas only 12-month-old infants succeeded in the former study.

Finally, Xu et al. (2001) provided evidence that when spatiotemporal evidence for a single object was strong, it was indeed kind representations that helped the infants override the spatiotemporal information, resulting in adultlike performance on the task. Xu et al. (2001) used the same complex procedure as that of Xu and Carey (1996) and found that only cross-kind shape differences (e.g., a cup and a bottle) led to successful individuation. When perceptual property differences were provided (e.g., a red ball and a green ball, or a small ball and a large ball), 12-month-old infants still failed to establish two distinct objects. Xu et al. (2001) hypothesized that kind representations were able to override spatiotemporal information because they are "summary representations." They allow the infants to encode the objects directly as a duck, a car, a cup, and a ball, and the infants hold such representations in short-term memory. These representations enabled the infants to encode the events according to kind membership and to override strong spatiotemporal evidence.[5]

[5]This interpretation is further bolstered by studies in object segregation, in particular when one contrasts studies by Needham and colleagues (Needham & Baillargeon, 2000; Needham, Baillargeon, & Kaufman, 1998) and Xu et al. (1999). First, Xu et al.'s (1999) task provided stronger spatiotemporal evidence for one object than did those of Needham and colleagues. Ten-month-old infants were fully habituated to the static display of a duck perched on top of a car (or the cup on the shoe), which may have given the infants spatiotemporal evidence that there was one object. In Needham's object segregation studies, in contrast, the objects (e.g., a box and a cylinder) were seen static, side by side, only for a few seconds before one was grasped and moved. Second, Xu et al.'s (1999) displays were highly ambiguous regarding a purely perceptual parse, whereas the featural information in the box/cylinder displays was unambiguous. The color, texture, and shape differences in the box/cylinder displays all supported the same parse. *(continued on next page)*

Characterizing the Two Systems of Object Individuation in Infants

The hypotheses presented in the last two sections are conjectures. If these hypotheses are correct, then they help characterize in more detail the two systems of object individuation in infants. I draw three conclusions from the studies I have reviewed in this section. First, the object-based individuation system is able to take into account perceptual property information in the absence of strong spatiotemporal information, even in infants. Second, strong spatiotemporal evidence can override perceptual property information in infants as well as in adults, which is characteristic of the object-based individuation system. Third, my claim stands that kind-based individuation system emerges at around 12 months of age and that kind representations can override spatiotemporal information.

One caveat must be noted: At present it is not known for sure whether the 9.5-month-old infants in Wilcox and Baillargeon's (1998a) study and the 10-month-old infants in Xu and Baker's (2001) study succeeded on their tasks by using perceptual property information or object kind information. I provided some analyses earlier suggesting that these successes were likely to be based on perceptual property representations, but this is clearly an empirical question. Studies currently are underway to address this issue.

MECHANISM OF CHANGE: HOW DOES THE KIND-BASED INDIVIDUATION SYSTEM DEVELOP?

In this chapter, I have reviewed evidence that the object-based individuation system is present in young infants and that a second, kind-based individuation system emerges toward the end of the first year of life. If this proposal is correct, we are now left with the crucial question of development: How do these two systems of individuation develop? Some researchers have argued that the object-based individuation system may be innate (e.g., Spelke, 1996), whereas others have proposed a learning account (e.g., Johnson, 2000). I am concerned here with how the second, kind-based system develops. I propose that learning names for object kinds may play a causal role in this process and that the infant's conceptual representations undergo fundamental changes as language development begins.

[5] *(continued)* The duck and the car (and the cup and the shoe), in contrast, were composed of multiple parts and multicolored. The bottom surface of the duck overlapped completely with the top of the car; the clearest discontinuity in terms of contour occurred between the head of the duck and the rest of the display, and the bill of the duck and the wheels of the car were all reasonably good candidates for objects on purely featural grounds. Therefore this display posed a difficult problem: The spatiotemporal evidence for one object was strong, and the featural information in support of the correct parse was weak. Under such circumstances, the infants must draw on kind representations to succeed on this task.

Empirical Findings on the Facilitation Effects of Labeling

Two findings in the literature directly motivated this line of inquiry. Balaban and Waxman (1996) found that words, but not tones, facilitate categorization in infants as young as 9 months. The infants were familiarized with a set of pictures of a given category—say, rabbits. Some infants heard a word when shown the picture on some of the trials, for example, "a rabbit." For other infants, a tone accompanied the presentation of the picture on some of the trials. The results showed that although both words and tones heightened the infants' attention to the objects, it was only in the word condition that the infants categorized the objects on the test trials. That is, they preferentially looked at an exemplar from a new category (e.g., a pig) compared with a new exemplar from the old category (e.g., another rabbit). These results suggest that in the presence of a label, infants group together the exemplars into a category more readily than in the absence of a label.

A post hoc analysis conducted by Xu and Carey (1996) provided a hint that language may play a role in acquiring kind concepts. Xu and Carey analyzed the looking time data from 10-month-old infants as a function of whether they understood any of the words that named the objects in the experiment (by parental report). There was a correlation between the two variables: The infants who were reported to understand some words looked longer at the single-object, unexpected outcome, whereas those who were not reported to understand any words did not. This finding is consistent with the idea that knowing the words for these objects is a means of establishing that they belong to different kinds, which in turn allows the infants to succeed in the object individuation task.

My colleagues and I have recently completed several studies investigating the role of labeling in object individuation. I (Xu, in press) presented 9-month-old infants with the same object individuation task as in Xu and Carey (1996), with the following crucial manipulation: As each object emerged from behind the screen, the infants heard a label for it in infant-directed speech on some of the trials. In the two-word condition, the infants heard two distinct labels: "Look, a duck" (when the duck was shown) and "Look, a ball" (when the ball was shown; see Fig. 5.7). In the one-word condition, the infants heard a single label applied to both objects (the duck and the ball): "Look, a toy." On some of the familiarization trials, the object was left stationary on the stage, and the infant's looking time was recorded. Half of these trials were labeled, and half were silent. On the test trials, the screen was removed to reveal either both objects (the duck and the ball—the expected outcome) or one of the two objects (the duck or the ball—the unexpected outcome). If the infants had established a representation of two objects, then they should look longer at the unexpected outcome of one object. The results showed that in the two-word condition, but not in

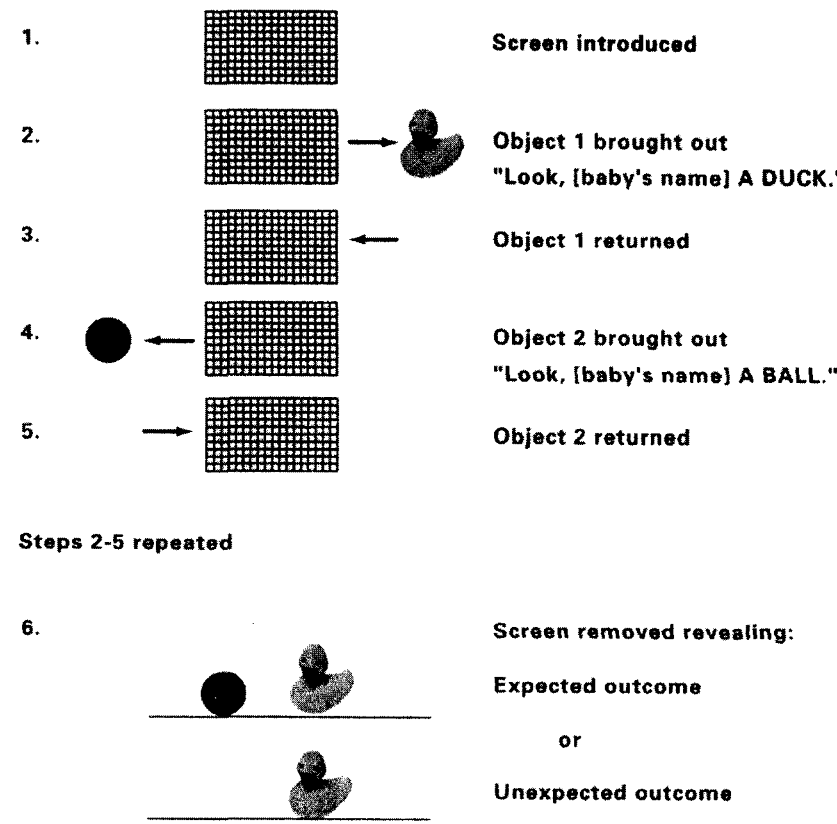

FIG. 5.7. Schematic representation of the experimental paradigm in Xu et al. (2001).

the one-word condition, infants looked longer at the unexpected outcome. Thus, on hearing two distinct labels, even 9-month-old infants were able to use the differences in object kind to establish a representation of two distinct objects. Furthermore, this effect was not simply due to hearing some words, because the infants failed the task when a single label was provided.

One may wonder whether the presence of two distinct words heightened the infants' attention to the objects, whereas the presence of a single word did not, and whether perhaps more attention led to a fuller encoding of object properties, which accounted for the success in the two-word condition. I analyzed the looking time data during familiarization, comparing the silent and the labeled trials. In both the two-word and the one-word conditions, infants' looking times were longer when the objects were labeled than when they were not. Therefore, the presence of labels did increase the infants' attention to the objects, but it increased their attention to the same extent in the two conditions. It appeared to be the presence of two distinct labels *per se* that led to the earlier success on this task at 9 months.

An immediate question arises: Are the facilitation effects language specific? Would other types of auditory information help as well? In the next two experiments, instead of using two words, I used two tones or two distinct sounds (e.g., a car alarm sound, or a spaceship sound produced by a gadget). As each object emerged from behind the screen, a tone or sound was played (e.g., "Look, [Tone/Sound 1] or "Look, [Tone/Sound 2]"). Under these conditions, 9-month-old infants did not look longer at the one-object unexpected outcome on the test trials. I also replicated the positive finding of the first experiment, using another pair of familiar objects (a cup and a shoe) as well as a pair of unfamiliar objects labeled with nonsense words (e.g., "a fendle" and "a toma"). These results suggest that infants can use distinct labels to help them succeed earlier in an object individuation task, and these facilitation effects may be language specific.

Most recently, I have conducted yet another version of these experiments, using another kind of auditory information, in this case emotional expressions. Infants have been found to be sensitive to the positive and negative valence of emotional expressions. Would infants use these contrasts to guide object individuation as well? Using the same object individuation task, I (Xu, 2001b) presented 9-month-old infants with unfamiliar objects and provided either two distinct words ("a blicket" and "a tupa") or two emotional expressions ("ah," signaling approval or satisfaction, and "ewu," signaling dislike or disgust). Infants looked longer at the unexpected outcome of one object on the test trials in the word condition but not in the emotional-expression condition, thus providing further evidence that words may indeed be special in facilitating object individuation.

To investigate further how powerful words are in facilitating object individuation in infancy, I asked whether the presence of labels could override conflicting perceptual information (Xu, 2001a). Nine-month-old infants were asked to solve the same object individuation task in which words were pitted against perceptual information. Four conditions were included, crossing two variables: number of objects (one or two unfamiliar objects) and number of labels (one or two nonsense words). That is, infants were shown either a single object emerging from both sides of the screen or two different objects emerging alternately from behind the screen, accompanied by either a single label or two distinct labels. On the test trials, the screen was removed to reveal a single object. The one-word–one-object condition served as a baseline, and the looking times of the other conditions were compared with it. The infants in the one-word–two-object condition did not look reliably longer than infants in the one-word–one-object condition. In contrast, the infants in both the two-word–one-object condition and the two-word– two-object condition looked reliably longer than infants in the one-word– one-object condition. In other words, the number of words appeared to have driven the infants' expectations of how many objects were behind the screen: If two words were used, the infants expected two objects behind the screen; if one word was used, the infants expected one object behind the screen. These findings suggest that words are powerful in guiding object individuation at 9 months—so powerful that they can override perceptual information.

What Exactly Is the Role of Labeling?

I raise three hypotheses regarding how labeling may play a causal role in establishing kind representations in infancy. First, infants (by 9 months, or perhaps even younger) may expect that words for objects map onto kinds of objects in their environment. Given this, the fact that one object is called a "duck" and an object seen on a different occasion is called a "ball" is sufficient evidence that these are two kinds of objects. If two kinds of objects are behind the screen in an object individuation task (e.g., Xu & Carey, 1996), then it follows that there must be two distinct objects. This may be a mechanism by which infants first establish what kinds of things are in their environment and use the newly formed kind representations to guide object individuation.

A second, and weaker, possibility is that distinct labels do not pick out kinds of objects for the infants *per se* but that they highlight the perceptual property–featural differences between objects. Once infants have taken further notice of these perceptual property differences, they are more likely to conclude that there must be two objects behind the screen.

A third possibility is that language may exert some influence on cognitive architecture in a rather sweeping fashion. Following Hermer-Vazquez, Spelke, and Katsnelson's (1999) proposal that language may serve as the vehicle for conjoining distinct parts of the cognitive architecture, I (Xu, 1999) hypothesized that learning names for things may allow infants to conjoin two aspects of object representations. Young infants, like adults, may have two distinct visual pathways for encoding object motion and location information (roughly speaking, the "where" pathway) and for encoding object features (roughly speaking, the "what" pathway). Early in infancy, perhaps these two pathways are largely separated, and there is little connection between the two. When infants first begin to learn words for objects, such as "a cup" or "a ball," two independently motivated word-learning constraints need to be met: the whole-object constraint and the taxonomic constraint (Markman, 1989). The whole-object constraint requires that words refer to whole objects as opposed to parts of objects; the taxonomic constraint requires that words should be generalized to members of the same kind. These constraints map onto the two aspects of object representations encoding "where" and "what" information, because the former establishes representations of whole objects and the latter provides a similarity metric that correlates with kind membership. In other words, if the two word-learning constraints need to be met, infants would have to pay attention to both the location information and the featural information. This conjecture also provides a way of connecting the literature on infant categorization (e.g., Eimas & Quinn, 1994; Quinn et al., 1993) and the literature on object individuation reviewed in this chapter. What the infant categorization literature may be tapping into are the characteristics of the "what" system, but this system is largely independent of the system that establishes distinct objects using spatiotemporal information, the "where" system. Kind-based object individuation, however, requires both "what" and "where" systems. We are at the beginning of this line of inquiry, and these conjectures clearly need further empirical investigation.

Is language the only mechanism for acquiring kind concepts? This is an open question. For example, infants may use functional information as a source of evidence that two objects are of different kinds: If a person can drink out of an object but uses a second object as a hammer, then infants may conclude that these are two distinct kinds of things with distinct functions. Infants may also use other correlated features to figure out the different kinds of objects in their environment. For example, if an object makes an internally generated "clunk-clunk" sound as it bounces across the floor, and another object makes a beeping sound, infants may conclude that it is highly unlikely that there is only one object involved. Studies currently are underway to investigate these possibilities.[6]

CONCLUDING REMARKS

In this chapter, I have presented evidence for how object individuation develops in infancy. I have also proposed a model in which an object-based individuation system develops by about 4 months of age and a kind-based individuation system begins to develop by about 12 months of age. Finally, I have suggested that the development of the second, kind-based individuation system may be driven by learning names for things toward the end of the first year of life.

Several questions remain unanswered by the research reviewed in this chapter: What is the relation between the object-based individuation system in infants and the mechanisms of object-based attention in adults? Are they one and the same mechanism? What is the role of language in developing the kind-based individuation system? What is the role of language in shaping infants' and children's conceptual representations in general? How do effects of language development on conceptual development bear on the age-old Whorfian hypothesis on language and thought? Would children acquiring different languages follow somewhat different developmental trajectories in their conceptual development? I hope that another century of infancy research will bring the answers to these questions.

[6] If language learning plays an important role in how human infants acquire object kind concepts, an obvious question to ask is: What about nonhuman animals? Do they also possess these two systems of individuation? Some evidence suggests that rhesus macaque monkeys have the object-based individuation system because they are able to use spatiotemporal information to keep track of objects (Hauser, Carey, & Hauser, 2000; Hauser, MacNeilage, & Ware, 1996). The evidence for the kind-based individuation system is more preliminary and less clear. Uller, Xu, Carey, and Hauser (1998) found that rhesus monkeys succeeded in the Xu and Carey (1996) task with a carrot and a piece of squash. However, these data are still open to alternative interpretations; for example, perhaps the rhesus monkeys did not keep track of individual items but rather foodstuffs, carrot stuff and squash stuff. If this is correct, it is not the same sense of individuation that is intended in the infant studies.

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