



ELSEVIER

Acta Psychologica 102 (1999) 113–136

**acta
psychologica**

Object individuation and object identity in infancy: The role of spatiotemporal information, object property information, and language

Fei Xu *

Department of Psychology, Northeastern University, 125 NI, Boston, MA 02115, USA

Received 28 July 1998; received in revised form 22 February 1999; accepted 23 February 1999

Abstract

Recent work on object individuation and object identity in infancy indicates that at least three sources of information may be used for object individuation and object identity: spatiotemporal information, object property information, and object kind information. Several experiments have shown that a major developmental change occurs between 10 and 12 months of age (Xu & Carey, 1996; Xu, Carey & Welch, in press; Van de Walle, Prevor & Carey, under review; Xu, Carey & Quint, in preparation): Infants at 10 months and younger readily use spatiotemporal information in object individuation and object identity tasks, but not until about 12 months of age are infants able to use object property or object kind information to do so. This paper proposes a two-part conjecture about the mechanism underlying this change. The first part borrows ideas from object-based attention and the distinction between “what” and “where” information in visual processing. The hypothesis is that (1) young infants encode object motion and location information separately from object property information; and (2) toward the end of the first year, infants integrate these two sources of information. The second part of the conjecture posits an important role for language. Infants may take distinct labels as referring to distinct kinds of objects from the onset of word learning, and infants use this information in solving the problem of object individuation and object identity. Evidence from human adults, infants, and non-human primates is reviewed to provide support for the conjecture. © 1999 Elsevier Science B.V. All rights reserved.

* Corresponding author. Tel.: +1-617-3733060; fax: +1-617-3738714; e-mail: fxu@neu.edu

PsycINFO classification: 7820

Keywords: Object individuation; Infant cognition

Human adults encounter a rich variety of material objects in their environment, from trees, rocks, animals, and people to desks, books, and computers. Our perceptual and cognitive systems automatically parse the world into discrete objects and often categorize them further in order to anticipate their behaviors and allow us to act upon them. As with any fundamental human cognitive capacity, cognitive and developmental psychologists alike are concerned with its origin. The basic questions are: Are these capacities part of our innate cognitive endowment? Do infants learn to perceive objects because of the environment they are born into? How much can experience shape the end state of these abilities even if these abilities are largely specified innately?

This paper looks at the development of object individuation and object identity in infancy, focusing on what sources of information are employed in object individuation and identity tasks and how object individuation, object categorization, and the emergence of language towards the end of the first year may causally interact with each other. Through this exercise, I hope to shed light on the question of the origin of knowledge and the process of conceptual change. The literature review is not meant to be comprehensive. Instead, I will focus on the work I have conducted with my colleagues and collaborators. Section 1 gives the background of the current approach to infant cognition. Sections 2 and 3 review the basic findings in the area of object individuation and object identity in infancy. Section 4 proposes a framework for understanding the developmental change uncovered by the empirical evidence and provides some preliminary evidence for the framework. Section 5 provides some concluding remarks.

1. Background

The last 20 yrs have witnessed important progress in the study of infant object perception and cognition. Fantz (1964) first pioneered the methodology of preferential looking with infants and showed that we can study perceptual discrimination in very young infants using this method. Subsequently, Spelke (1985) and others extended the use of this method to ask questions beyond simple perceptual discriminations. For example, do infants perceive objects as three-dimensional? Do infants understand that objects are cohesive and do not leave parts of themselves behind while moving through space? Do infants comprehend that two solid objects cannot occupy the same space at the same time? Under what conditions do infants arrive at representations of two as opposed to one object in an event?

The general method of these studies exploits the fact that infants (as well as adults) tend to look longer at new and unexpected events. Infants are shown the same event or objects repeatedly, and their looking times are recorded. With each

repetition, the infant's looking time declines; that is, infants "habituate." When the infant's looking time has reached some pre-set criterion (usually 50% of the initial looking times summed over three trials), test trials begin. Infants are alternately shown an expected outcome (an outcome that is consistent with adults' understanding of the physical or social world) and an unexpected outcome (an outcome that is inconsistent with adults' understanding of the physical or social world). If infants have the same understanding of the events shown during habituation as adults, they should look longer at the unexpected outcome relative to the expected outcome. This particular version of the methodology is often called the "visual preference for violation of expectancy" paradigm. It is in one sense akin to the measure of reaction time: It takes the infant longer to process an anomalous event/outcome than one that is consistent with their general model of the world.

Many researchers have contributed extensively to the literature of how infants understand the physical world around them. Spelke and her colleagues (e.g., Spelke, 1990, 1996; Spelke, Breinlinger, Macomber & Jacobson, 1992) have discovered several principles that guide young infants' perception and reasoning of physical objects. First, physical objects are cohesive; they move as wholes, and they do not leave parts of themselves behind. Second, objects obey principles of continuity and solidity; they move on spatiotemporally continuous paths, and two objects cannot occupy the same space at the same time. Third, objects act on each other upon contact; that is, there is no action at a distance. These principles stay at the core of our mature understanding of physical entities as adults. Against the backdrop of a strong Piagetian tradition in developmental psychology, which claims that young infants experience a "blooming, buzzing confusion" as opposed to coherent three-dimensional objects in their surroundings, Spelke and her collaborators have shown that some of our deepest beliefs about how physical objects should behave may have their roots in early infancy, perhaps given innately. Other researchers have focused on infants' reasoning about specific types of physical events such as occlusion and support, and how infants perceive the causal relations among objects (see Bailargeon, 1994, 1995; Leslie, 1994 for reviews).

These research enterprises have been followed up by many laboratories. Much controversy has been generated over (a) the nature of the infants' representations when they show such early competence; (b) how these new findings should be reconciled with the highly robust and replicable findings by Piaget and his associates; and (c) how these early representations are related to the mature cognitive system in adults (e.g., Bogartz, Shinsky & Speaker, 1997; Munakata, McClelland, Siegler & Johnson, 1997; Spelke, 1996).

2. Object individuation and object identity: previous work

My research focuses on a particular aspect of object representations, namely the issue of object individuation and object identity. Specifically, how do infants arrive at representations of multiple objects and trace their identity through time and

space? What sources of information do infants employ in this process? We know that adults use at least three sources of information in object individuation: Spatiotemporal information, object property information, and object kind information. Spatiotemporal information refers to generalizations such as one object cannot be at two places at the same time and objects travel on spatiotemporally continuous paths. Object property information refers to how we can use general Gestalt principles of good form, good continuation, and relevant featural differences (e.g., color, shape, size, or texture) in object individuation. Lastly, object kind information refers to our knowledge about specific categories of objects. For example, size change may or may not indicate a change of identity depending on whether the entity under consideration is biological or not. In other words, our criteria for object individuation and object identity are kind-relative.

Bower (1974) was the first to suggest that young infants may use spatiotemporal information to individuate objects before they use object property information to do so. In a series of experiments, Bower found that before five months of age, infants' tracking behavior was interrupted if a moving object stopped abruptly, but not if an object (e.g., a toy bunny) had apparently turned into a different object (e.g., a toy truck). He concluded that infants at five months represent moving and stationary objects as distinct objects: When an object stops moving, it is no longer the same object. However, when a toy bunny apparently has turned into a toy truck, infants up to five months are unable to use the property differences to arrive at a representation of two distinct objects. As we will see below, although Bower's particular spatiotemporal rule may be incorrect and his results have been difficult to replicate (see Xu & Carey, 1996 for a more detailed review of these studies), his insight about the relative importance of spatiotemporal and object property information in early object individuation may well be correct.

In recent years, much more research has been conducted on how infants resolve the ambiguity concerning the number of objects in an event or a scene. Ambiguity in object individuation can arise in at least three ways. First, two fully visible adjacent segments may or may not belong to the same object. (This problem of perceptual grouping has also been an important topic of research in adults, e.g., Feldman, 1999.) Second, two segments may be occluded at their boundary such that it is ambiguous whether they belong to a single object or not. (This problem of amodal completion has also been an important topic of research in adults, e.g., Tse, 1999; Van Lier, 1999.) Third, infants are constantly in situations where they have to determine whether two encounters with an object are one object seen on two different occasions or are two numerically distinct objects.

Spelke and her colleagues have done several seminal studies with young infants addressing the issue of object individuation under all three of these ambiguous conditions. First, Spelke, Breinlinger, Jacobson and Phillips (1993) found that infants are relatively insensitive to Gestalt properties of good form and good continuation when objects are fully visible. Rather they utilize factors such as relative motion in object individuation. Second, Kellman and Spelke (1983) reported a set of very important studies concerning the use of Gestalt principles in infants when segments were occluded at their boundaries. They found that there was little

evidence that four-month-old infants would use good continuation or the contrast in color or shape to infer the existence of one or two objects. Instead, common fate (that two segments move together behind an occluder) appears to be the principal way by which infants decided whether two segments were connected behind an occluder. Third, Spelke, Kestenbaum, Simons and Wein (1995) showed that under conditions of full occlusion, young infants use spatiotemporal discontinuity as a source of information for deciding whether there were one or two objects behind the occluders. That is, if an object appears to have “jumped” from point A to point B without traversing a connected path in between, infants conclude that there must be two distinct though featurally identical objects.

These studies laid the foundation for the main focus of this paper. I will report several sets of studies conducted by my colleagues and me on the use of spatiotemporal information, object property information, object kind information, and the role of language in object individuation.

I make two claims. First, young infants initially use primarily spatiotemporal information, that is, information about object location and object motion, to individuate objects. Although young infants are sensitive to object properties and they can use them in categorization tasks, information about object properties is largely ignored in object individuation. Toward the end of the first year, infants begin to use object property and object kind information for the purpose of object individuation. I propose a possible brain maturational mechanism to account for this development. Second, at the end of the first year, language in the form of labeling may play an important role in reorganizing the infants' conceptions of the world. Words for objects may help infants pick out the kinds in their environment and now infants can use kind membership for object individuation.

3. Basic findings

Imagine the following scenario: Two screens are put on a puppet stage with some space in between them (Fig. 1). An object, say a duck, emerges from behind the left screen then returns behind it. After a short pause, a physically identical duck emerges from behind the right screen then returns behind it. No object ever appears in the space between the screens. How many objects are behind the screen? For adults, the answer is clear: two identical ducks. We know that objects traverse spatiotemporally connected paths. If an object appears to have jumped from one point in space to another point in space without traversing a connected path in between, then there must be two objects, even though they may be featurally indistinguishable. Spelke et al. (1995) and Xu and Carey (1996) asked whether the answer was similarly clear for infants at 4 months and at 10 months. Both age groups were shown the above event repeatedly. On the test trials, the screens were removed to reveal either two identical objects (the expected outcome) or just one object (the unexpected outcome). Infants' looking times were recorded and compared to their baseline preference for the two outcomes. At both 4 and 10 months of age, infants looked longer at the unexpected outcome, suggesting that they can use at least one form of spatiotemporal evidence,

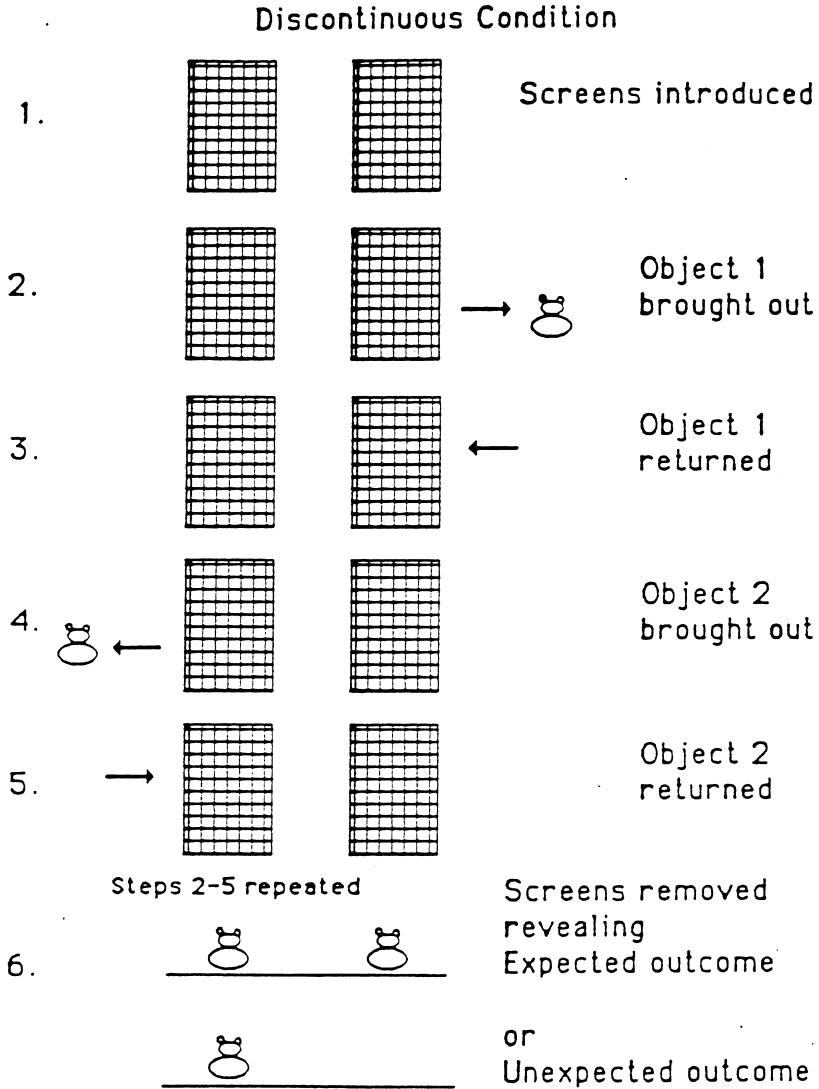


Fig. 1. Schematic representation of the discontinuous condition in the study by Spelke et al. (1995).

namely spatiotemporal discontinuity, to decide how many objects are involved in an event.

Now imagine the following scenario: One screen is put on a puppet stage. A duck emerges from behind the screen and returns behind it, and then a ball emerges from behind the same screen and then returns (Fig. 2). How many objects are behind the screen? For adults, the answer is clear: Two, a duck and a ball. But since there is only a single screen occluding the objects, there is no clear spatiotemporal evidence that there are two objects. We must rely on our knowledge about object properties or

Property/Kind Condition

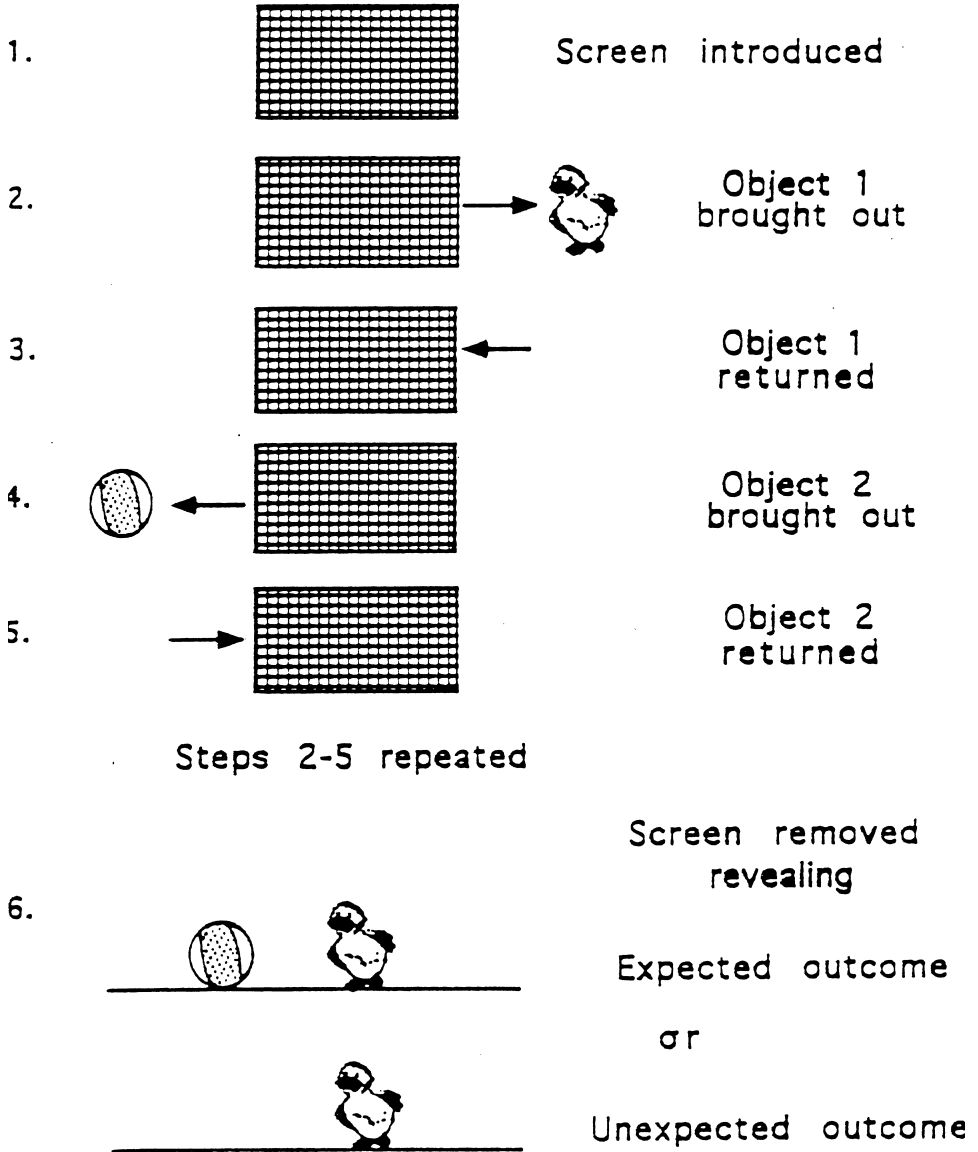


Fig. 2. Schematic representation of the property/kind condition in the study by Xu and Carey (1996).

object kinds to succeed at this task. Xu and Carey (1996) asked whether the answer was also clear for infants. In a series of studies, infants were shown the above event. The contrast was either at the superordinate level (e.g., a duck and a ball; an

elephant and a truck¹) or at the basic level (e.g., a cup and a ball). On the test trials, the screen was removed to reveal either the expected outcome of two objects or the unexpected outcome of only one of the two objects. If infants have the same expectations as adults, they should look longer at the unexpected outcome. The results, however, were surprising: 10-month-old infants failed to draw the inference that there should be two objects behind the screen, whereas 12-month-old infants succeeded in doing so. Control conditions established that the method was sensitive. Ten-month-old infants succeeded at the task if they were given spatiotemporal evidence that there were two numerically distinct objects, e.g., if they were shown the two objects *simultaneously* for 2 or 3 s at the beginning of the experiment.

The findings reviewed so far show that infants can use two types of spatiotemporal evidence (i.e., spatiotemporal discontinuity or two objects seen simultaneously) in object individuation tasks. However, it is not until about 12 months of age that they are able to use object property or kind information to do so.

These results are surprising because earlier visual and manual habituation studies have shown that 10-month-olds and infants much younger are sensitive to the differences between cups and trucks, or ducks and balls (e.g., Cohen & Younger, 1983; Eimas & Quinn, 1994; Oakes, Madole & Cohen, 1991; Quinn, Eimas & Rosenkrantz, 1993). For example, if three- and four-month-old infants are habituated to pairs of objects from the same category, say cats, they will dishabituate to an object from a different category, say dogs, while remaining habituated to a new exemplar from the same category, i.e., another cat. Furthermore, Xu and Carey (1996) have shown that infants are sensitive to object properties under the circumstances of their experimental paradigm: It takes infants longer to habituate to a duck and a car alternately appearing from each side of the screen than to a car repeatedly appearing from behind the screen. Xu and Carey (1996) concluded that the reason why 10-month-old infants failed at their object individuation task was because they lack representations of object kinds such as *duck*, *truck*, *animal*, *vehicle*, *cup*, *bottle*, and *book*. The property differences which infants under 10 months of age are sensitive to may be irrelevant to object individuation.

In search of convergent evidence for Xu and Carey (1996), Xu, Carey and Welch (in press) conducted a series of experiments using a paradigm that reduced the information processing demand on the infant. In the Xu and Carey (1996) paradigm, success required the infants to *recall* the representation of the first object, including its properties or its kind membership, and compare this representation to that of the second object. Perhaps the task was taxing the infant's memory capacity and the failure at 10 months reflects an information processing limitation on short-term memory, rather than the unavailability of the relevant kind concepts. In the second series of studies, ambiguity regarding object individuation was introduced not by

¹ Here we consider the contrasts between a duck and a ball as well as between an elephant and a truck as superordinate level contrasts even though the duck and the elephant were toys. Mandler and her colleagues have shown that infants seem to be able to reason about toy animals as if they were real animals (e.g., Mandler & McDonough, 1996).

occlusion, but by shared boundaries, as shown in Fig. 3. How many objects are there in this array? Adults responded that there were two objects, recognizing that the top half was a duck and the bottom half was a car.

10- and 12-month-old infants were presented with the same array as that in Fig. 3 and asked how they would segment it (a different contrast, a cup on top of a shoe, was used in one of the studies). Infants were habituated to the duck-car array with a hand poised a few centimeters above it. After habituation, the hand grasped the top object and lifted, revealing either the expected, apart outcome of just the top object being lifted or the unexpected, together outcome of the duck/car or cup/shoe object being lifted as a single piece (Fig. 3). Notice that in these experiments, both objects were continuously visible and no short-term memory demands were placed on the infants.

The results converged nicely with those of Xu and Carey (1996). At 10 months, the infants did not look longer at the unexpected, together outcome; they failed to use the contrast between the duck and the car, or the cup and the shoe, to infer that

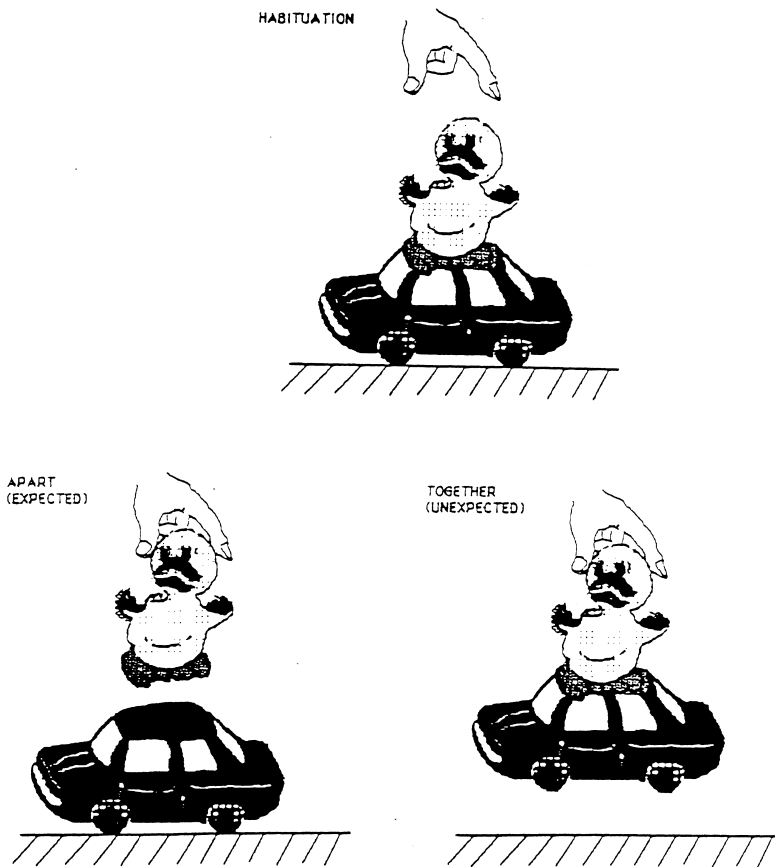


Fig. 3. Schematic representation of the duck-car experiments by Xu et al. (in press).

there were two individual objects in the array. At 12 months, however, the infants succeeded at the task, looking longer at the unexpected, together outcome. Furthermore, as in the first series of studies, when 10-month-old infants were given spatiotemporal evidence that there were two objects (e.g., if the objects were briefly moved, laterally, relative to each other at the beginning of each habituation trial), then they looked longer at the unexpected, together outcome.

Thus, data from two series of experiments that place very different information processing demands on the infant provide convergent evidence for the claim that infants only begin to use object property or kind information in object individuation at the end of the first year.

Recently, yet a third series of studies has been completed and the results converge with the two series of studies described above (Van de Walle, Prevor & Carey, under review). In these studies, a manual search measure was used instead of looking time. Ten- and 12-month-old infants were trained to reach into a box to retrieve all the objects inside. The box was covered with fabric so the infants could not see what was inside. Two types of trials were included. On two-object trials, infants watched the experimenter pull out an object, e.g., a toy telephone, return it to the box, then pull out a second object, say a toy duck, and return it to the box. On a one-object trial, the experimenter pulled out the same object, e.g., the toy telephone, twice. Infants were then allowed to reach into the box to retrieve the objects. Both 10- and 12-month-old infants reached in and found one of the two objects. They were allowed to play with the first object for a short while and then the object was taken away. Unknown to the infants, the second object had been removed from the box through an opening at the rear of the box. The measure of interest was how persistently the infants reached for the second object. At 12 months, infants reached persistently for the second object on the two-object trials, both in terms of the number of reaches and the duration of the reach. On the one-object trials, they either did not reach the second time or only did so cursorily. In contrast, the 10-month-old infants behaved the same way on both types of trials: they only reached cursorily. Ten-month-olds reached persistently, however, when the two objects were shown simultaneously before they were placed in the box, i.e., when unambiguous spatiotemporal evidence was provided.

These manual search studies placed greater information-processing demands on the infant because the infant's object representation has to be "strong enough" to direct action (see Munakata, McClelland, Johnson & Siegler, 1997, for a detailed discussion of these issues) and the literature suggests that infants often succeed in a looking time version of a task earlier than a manual search version of the same task (but see Van Hofsten, Vishton, Spelke, Feng & Rosander, 1998 for a different proposal). Nonetheless, the results from these manual search studies are completely consistent with those from the looking time studies. This convergence suggests that the developmental change between 10 and 12 months is orthogonal to infants' ever improving information processing capacity. This change may be due to the emergence of representations of object kinds.

Some recent studies (Wilcox & Baillargeon, 1998a; Wilcox & Baillargeon, 1999; Needham, 1998; and Needham & Baillargeon, 1998), however, have found earlier

sensitivity to using property information in object individuation in somewhat different and perhaps simpler paradigms. I note here briefly that the earlier competence seems very fragile and highly sensitive to the smallest variation in procedure. And even if some early competence is found in young infants, it still seems likely that there exists a major developmental change towards the end of the first year. That is, the three paradigms used in the studies described above make very different information processing demand on the infant, but they provide convergent evidence for the 10 to 12 months developmental change.

4. Mechanism of change

What is the mechanism underlying this developmental change? I will sketch a two-part conjecture, discuss the evidence to date for each part, and speculate about how the two parts may be complementary. The first part hypothesizes a maturational change that allows the infant to integrate object location information (“where”) with object property information (“what”). The second part hypothesizes that toward the end of the first year, infants may use distinct labels as signals to distinct object kinds, so that language may play an important role in the construction of kind representations.

4.1. Part I: integrating ‘what’ and ‘where’ systems

Part one of the conjecture borrows ideas from work on adult visual processing and attention, and ideas from neurophysiology and neuropsychology about visual pathways in humans and non-human primates. The main idea of the proposal is as follows (see Leslie, Xu, Tremoulet & Scholl, 1998 for a similar proposal).

I postulate a theoretical construct, which I call an “object index.” An object index functions as a pointer to an object. Like a finger pointing to something in the environment, the index itself does not inherently represent any of the properties of the object it points to. If object property information is part of the object representation, it has to be “bound” to the index. Furthermore, we only have three or four indexes in the mechanism responsible for establishing object tokens.

How is index assignment established? Several principles apply: A distinct object can attract only a single index. Once assigned, an index sticks to the object even as the object moves through space. Furthermore, because there are only three or four indexes, they need to be de-assigned before they can be assigned to a new object. Lastly, indexes are assigned to objects primarily by location. As in object-based attention, however, the indexes are not assigned to locations themselves but to the objects in the locations. In case of absent or ambiguous location information, an index can be assigned based on object property information. However, this may be a later development in infancy.

This idea of object indexing mechanism recalls two theories from the visual processing and visual attention literature. First are recent theories of object-based attention. The idea of an object index is directly inspired by constructs such as an

“object file” (Kahneman & Treisman, 1984; Kahneman, Treisman & Gibbs, 1992), a FINST (Pylyshyn, 1990; Trick & Pylyshyn, 1994), or a “which” system for establishing object tokens (Kanwisher & Driver, 1992). Second is the distinction between the “what” and the “where” systems of visual processing. Evidence from neurophysiology and neuropsychology suggests that object property information and object location information may be processed, to a large extent independently, by anatomically distinct circuits in the brain (Schneider, 1969; Ungerleider & Mishkin, 1982; Van Essen & Maunsell, 1983). Originating from the primary visual cortex, the ventral pathway to the temporal lobe (the “what” system) is implicated in recognizing object properties such as color, shape, and category, whereas the dorsal pathway to the parietal lobe (the “where” system) is implicated in processing object location information (but see Goodale, 1995 for a different proposal).

I hypothesize that the process of object individuation is the process of assigning object indexes to distinct object tokens. The “what” system encodes object properties and the “where” system encodes object location information. The object indexing system receives its input from the “what” and the “where” systems. Once assigned, each object index points to a single object and keeps track of it through space and time. Early in development, information about object properties and information about the locations of objects are processed separately and only the latter is fed into the object indexing system. Thus, young infants use primarily location information in assigning indexes. At the same time, the “what” system is operative early, allowing the infant to perceive color, shape, among other visual attributes, and to categorize objects (see Atkinson, 1993 for a review). However, there is little or no connection between the “what” system and the object indexing mechanism, resulting in the infant’s inability to use object property information in object individuation (Fig. 4). Toward the end of the first year, a connection is established between the “what” system and the object indexing mechanism and the infant is now capable of using object property information to establish distinct object tokens (Fig. 5).

How does the object indexing framework account for the recent findings with infants? The object index framework interprets them in terms of indexing by location, using spatiotemporal information. As described earlier, Spelke et al. (1995) showed infants two screens on a puppet stage, separated by some space between them. A rod is brought out from behind the left screen and moves to the left side of the stage, which prompts the indexing mechanism to assign an object index to that object and moves the index as the object moves. When the object moves back behind the left screen, the index continues to point at it. When the second rod appears from behind the right screen to the right side of the stage, the indexing mechanism assigns a second, distinct index based on location information and spatiotemporal discontinuity. On the test trials, the screens are removed to reveal two identical rods (the expected outcome) or just one rod (the unexpected outcome). Infants look longer at the unexpected outcome of one rod because they detect a discrepancy between what is shown on the stage and how many indexes have been assigned during familiarizations.

The findings of Xu and Carey (1996) may be accounted for if we assume that the object property information is not accessible to the indexing mechanism. Recall that

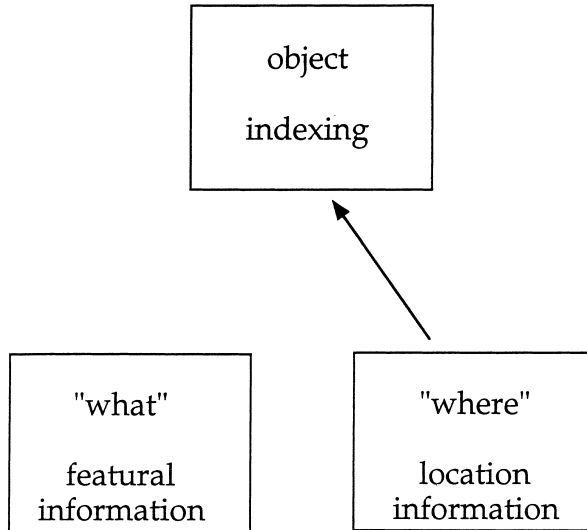


Fig. 4. The younger infant's object indexing system.

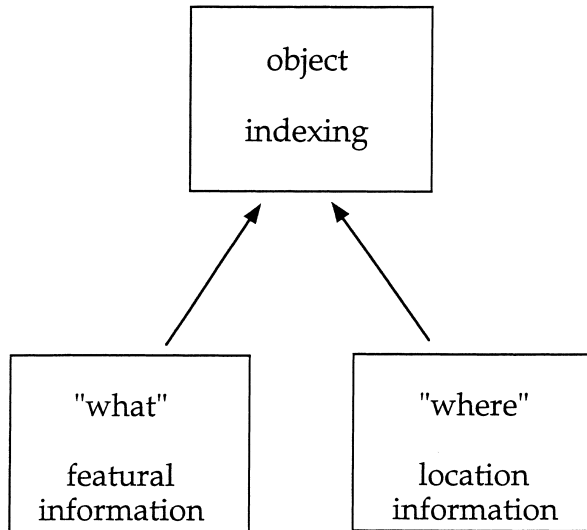


Fig. 5. The older infant's object indexing system.

the 10-month-old infants in Xu and Carey's studies were sensitive to object properties, but when the objects were shown one at a time, the infants were not able to use the property differences to establish representations of two distinct objects. In contrast, when the objects were shown simultaneously before familiarization, that is, clear spatiotemporal evidence was given that there were two objects, infants

succeeded in establishing two distinct objects behind the occluder. In other words, at 10 months of age, the indexing system may be driven solely by the “where” system but not the “what” system. By 12 months, however, the property differences of objects appearing in succession force the assignment of a second index. One plausible explanation is that the change between 10 and 12 months in these tasks reflects increased integration of the “what” and the “where” systems.

So far, however, the object indexing mechanism is postulated post hoc in order to account for these data. Is there more direct evidence suggesting the separation of “what” and “where” information and more importantly, the integration of these two sources of information in human infants and adults?

Simons (1996) found that in normal adults, object identity and object location information are processed separately and the integration of the two may depend on effortful verbal encoding. Participants of these studies were shown arrays of five objects (e.g., cap, keys, stapler) on a computer screen (Fig. 6). The subjects viewed the array for a fixed amount of time, then after a pause, a second array was presented. The second array was either identical to the first array or different in one of three ways: (1) In the configuration change condition, one of the objects moved to a new location; (2) in the identity change condition, one of the object was replaced by a new object; and (3) in the switch condition, two of the objects switched positions. The participants made a same/different judgment between the first and the second arrays.

Two findings are of particular interest. First, in all versions of the studies, participants were much more accurate in judging a configurational change than either the identity change or the identity switch, even when performance was above chance for all conditions. Second, when novel shapes were used and verbal shadowing was used to prevent the participants from labeling the objects, performance in the switch

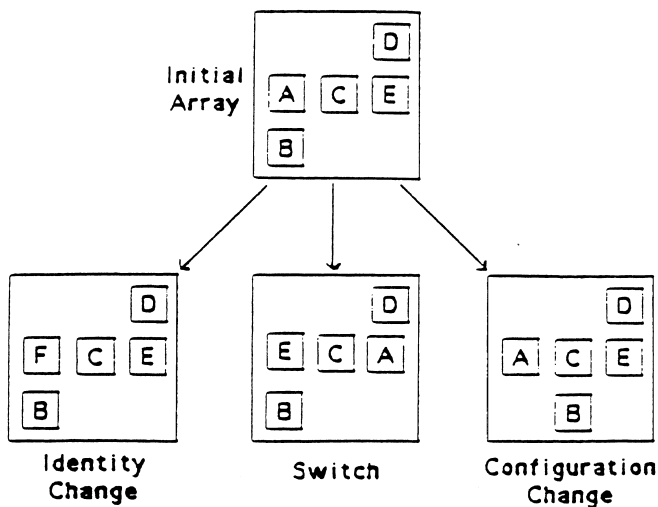


Fig. 6. Schematic representation of the three types of change in the study by Simons (1996).

condition and in the identity condition dropped to chance or barely above chance while performance in the configuration condition was virtually unaffected. These results suggest that object identity and object location are processed separately and verbal labeling may be a necessary component for integrating the two sources of information.

Most recently, two infant studies have begun to address the issue of integrating the “what” and the “where” information. Condry, Levine and Simons (1999) reported two experiments with 10-month-old infants using the basic design of Simons (1996). The dependent measure was how long the babies looked at the configurational change compared to the switch and the identity changes. Preliminary results suggest that infants were far better at detecting the configurational change than if two objects switched positions, even though they were able to detect the change when a new object replaced one of the original objects. Similarly, Park and Xu (1999) found that using the two-screen paradigm of Spelke et al. (1995), seven-month-old infants dishabituated to a change of object identity (i.e., if one of the two objects has been replaced by a new object) but they did not dishabituate when the two objects switched positions. These studies are still in progress, but they provide some initial evidence for our conjecture.

At the neurophysiological level, a recent study by Rao, Rainer and Miller (1997) asked where the “what” and “where” information is integrated in a study with rhesus monkeys. They hypothesized that although object properties and object location information may be processed separately by the ventral and the dorsal pathways, both sources of information are needed for action. To investigate whether pre-frontal cortex is where these two sources of information are integrated, Rao et al. recorded the activity of 195 neurons in two monkeys. The task demanded both “what” and “where” working memory. On each trial, the monkey started by fixating on a spot in the center of a computer screen (Fig. 7). A sample object, e.g., a bell, was briefly presented at the fixation point. After a delay of one second (the “what” delay), two test objects were briefly presented at two of four possible extrafoveal locations. One of them matched the sample, the other did not. After another delay of one second (the “where” delay), the monkey had to make a saccade to the remembered location of the matching object. Note in this task, both what the object was and where it was were required in order for the monkey to make the correct response. The results of this study showed that about 7% of the 195 pre-frontal neurons apparently specialized in encoding “what” information—they were only active during the first, “what” delay. About 41% of the neurons specialized in encoding “where” information – they were only active during the second, “where” delay. More importantly, the rest of the cells, 52%, showed significant activity during both the “what” and the “where” delays. Further analyses showed that among these what-and-where cells, 44% of them were truly integrating object identity and object location information; that is, they were most active when a matched object appeared in a matched location and less active when a nonmatch object appeared in a matched location. The other 56% of the what-and-where cells switched modes between keeping track of what information and where information.

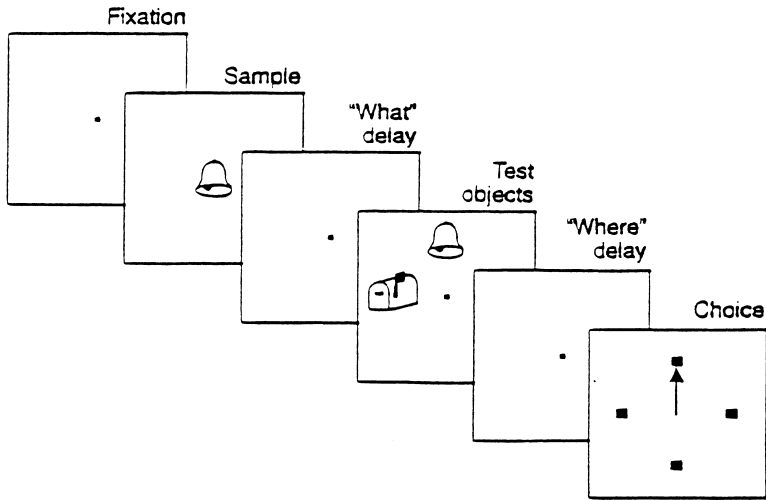


Fig. 7. Schematic representation of a trial in the study by Rao et al. (1997).

Taken together, these studies provide some initial evidence that (1) human infants encode object location and object property information separately for most of the first year and it is plausible that these two sources of information become integrated towards the end of the first year; (2) pre-frontal cortex may be the locus of such integration, at least in rhesus macaque monkeys; and (3) in human adults, verbal labeling may be one way to integrate “what” and “where” information.

4.2. Part II: the role of language: count nouns refer to kinds of things

Part II of our conjecture opens a whole new “can of worms.” I hypothesize that the process of learning count nouns for object kinds plays a causal role in the infant’s construction of kind concepts.

Some philosophers and psychologists of language have argued that mature systems for object individuation and object identity crucially depend on our representations of kinds, especially a subset of kinds called “sortals.” A sortal refers to the conceptual counterpart of a count noun such as “dog,” “chair,” or “person” (Geach, 1957; Gupta, 1980; Hirsch, 1982; Macnamara, 1987; Wiggins, 1980; Xu, 1997). The sortal *dog* provides criteria of individuation: It tells us what counts as one instance of the kind *dog*; we know if we are in the presence of one, two, or three dogs. The sortal *dog* also provides criteria for numerical identity: When a dog, Rover, dies, it ceases to exist even though we can trace a spatiotemporally continuous path between Rover and its body; when two dogs, Max and Maxine, disappear and reappear from behind a tree, we know which dog is Max and which is Maxine. In everyday speech, mass nouns such as “sand,” “water,” and “milk” also refer to kinds, but they do not provide criteria for individuation and identity (e.g., some sand plus some sand is more sand; “a sand” is ungrammatical) therefore they are not “sortals.”

One way to apply the above conceptual analysis of sortals to the empirical studies of object individuation in infancy is to imagine how adults would succeed at these tasks. In the Xu and Carey (1996) experiments, when the first object, say a toy duck, appears from behind the screen, adults encode it as “a duck.” When the second object, say a ball, appears from behind the same screen, adults encode it as “a ball.” We infer the presence of two objects because we know that “a duck does not usually turn into a ball.” Underlying this reasoning is our belief that ducks and balls are two different *kinds* of things: Ducks have a duck essence and balls have a ball essence. These essences, i.e., deep properties, determine the surface features (a phenomenon called “psychological essentialism,” Medin & Ortony, 1989). Similarly, in the Xu, Carey and Welch (in press) experiments, adults encode the duck-car display as consisting of two objects of different kinds, a duck and a car. Again, our beliefs tell us that different kinds of objects are not usually connected with each other even when they are adjacent, so the duck should not be lifted with the car.

If this analysis is correct, one way of thinking about the 10-month-old infants’ failure is that they do not represent kinds of things such as duck or ball yet. Furthermore, the analysis above on the relation between object individuation and sortals/kinds opens the door for speculating on the relation between learning words such as “duck” and “ball” and succeeding at the Xu and Carey task. That is, perhaps learning words such as “duck” and “ball” plays a role in the construction of kind representations.

Before any further discussion, however, we need to consider an alternative way by which infants at 12 months might succeed at these object individuation tasks: They could have used object property, as opposed to object kind, information. Adults, when faced with unfamiliar objects, can certainly use the property differences among the objects (e.g., shape, color, texture, etc.) to infer the number of objects in an event. In order to test this alternative hypothesis, we have recently completed a series of experiments with 12-month-old infants, probing their use of object property (e.g., color, size) and object kind information in object individuation (Xu et al., in preparation). These studies employed the experimental procedure of Xu and Carey (1996), alternately showing the infant two objects emerging from behind a single screen and, in effect, asking them how many objects there are on the test trials. In the first experiment, we familiarized the infants to two objects which differed only in color (e.g., a red ball and a green ball). Although infants were sensitive to the color contrast, they did not look longer at the unexpected outcome of one object on the test trials. In the second and the third experiments, we familiarized the infants to two objects which differed only in size or the combination of size, color, and surface pattern. Again, infants failed to look longer at the unexpected outcome of one object on the test trials even though they were sensitive to the property contrasts. In the last experiment of this series, we contrasted two types of shape change: within kind (e.g., two cups, one a sippy cup with a lid and two handles and the other a regular cup with no lid and only one handle) and cross kind (e.g., a cup and a bottle). The objects were identical in size, color, and surface pattern, but differed in overall shape. The results were quite interesting: The infants habituated at the same rate in both cases, that is, they found the within kind shape change as noticeable as the cross kind shape

change. However, only the infants in the cross kind condition succeeded at the task by looking longer at the unexpected outcome of one object on the test trials. These results suggest that 12-month-old infants represent the distinction between kinds and properties, and they may indeed be using kind information as opposed to property information for object individuation.²

The developmental change we have discovered occurs between 10 and 12 months, which coincides with the time window of the first sign of language comprehension in most infants. Furthermore, children's earliest words tend to be names of kinds of physical objects, e.g., doggie, cup, and ball. This coincidence immediately raises questions about the possible relation between language and cognition in acquiring kind concepts. There are at least three possibilities. First, infants have to be able to use object kind information to individuate objects before they can learn words for kinds of objects. That is, concepts are acquired before the words which map onto these concepts. Second, learning words for kinds of objects may be the driving force behind the acquisition of kind concepts. That is, language learning may be one way of inducing conceptual change. Third, the processes of acquiring kind concepts and learning words for them are intertwined and neither can be identified as either solely the cause or the effect.

The rest of this section will review some recent empirical results and try to build a case for the second possibility, namely that language may drive the construction of kind concepts in infancy. Some of the experimental work is still in progress, so we can only speculate for the time being.

Indirect evidence from Xu and Carey (1996) provides some hints that perhaps the object individuation task is related to early language comprehension. In two of the experiments, the parents of the infants filled out a short vocabulary questionnaire reporting whether their infants understood the words for the objects we used in the experiments. When the 10-month-old infants, who failed at the object individuation task as a group, were divided into infants who understood some of the words (e.g., ball, cup) as opposed to none of the words, the former group did significantly better on the task than the latter. Of course this is merely a correlation; it is unclear whether there is a causal relation between the two achievements.

Recently, Waxman and her colleagues (Balaban & Waxman, 1996; Waxman & Markow, 1996) demonstrated that hearing a word facilitates 9- and 13-month-old infants' performance in a categorization task. The infants were familiarized with a set of pictures of various exemplars from a single category, say rabbits. On some of the familiarization trials, the infants heard the word "rabbit" when the picture was shown. On the test trials, the infants were given two pictures simultaneously: a new picture of a rabbit and a picture of an exemplar from a different category, e.g., a pig. Balaban and Waxman found that 9-month-old infants who heard the word during

² Adults, of course, can establish representations of two objects when shown these property contrasts (e.g., a red ball vs. a green ball). Presumably this is because adults have learned that balls do not change color or size randomly. The infants, however, are yet to acquire the knowledge that balls do not change color or size. They have not learned these kind relative criteria for object individuation and object identity.

familiarization spent more time looking at the picture of the pig compared to infants who did not hear the word or the ones who heard a tone. They suggest that infants took the word as signaling the presence of a category. These findings raise the intriguing possibility that perhaps in the Xu and Carey paradigm, if infants hear two different words as the objects emerge from behind the screen, they will use the words as indicating the presence of two kinds and succeed earlier on the task.

We have begun a series of experiments with 9-month-old infants to investigate whether they will use distinct labels as signals to distinct object kinds (Xu, 1998). In the first experiment, 36 infants were assigned to one of three conditions: the two-word condition, the one-word condition, or the baseline condition. In the two-word condition, infants were familiarized with two objects, say a duck and a ball, emerging from behind the screen one at a time, and when each object came out, the baby heard “Look, a duck” or “Look, a ball” in infant-directed speech. For four of the familiarization trials, the object was left stationary for the infant to look at until she turned away. Two of these trials were accompanied by a word and the other two were silent. On the test trials, the screen was removed, revealing one or two objects. The procedure for the one-word condition was the same as in the two-word condition, except that the infant only heard one word, “a toy,” when each object emerged from behind the screen. In the baseline condition, infants were shown the outcomes of one or two objects without familiarizations.

We found that the infants in the two-word condition looked longer at the unexpected outcome of one object but the ones in the one-word condition did not. Along with the findings by Waxman and her colleagues, these data suggest that even very young infants have an expectation that words (perhaps only words referring to objects) pick out kinds. If two objects are referred to with two different words, they must belong to two different kinds, therefore there must be two distinct objects behind the screen. An immediate problem with this interpretation is that perhaps the presence of two words simply drew the infants’ attention to the objects, which led to better encoding of the properties of the objects. On this alternative view, distinct labels do not pick out distinct kinds *per se*, but rather they alert the infant to pay more attention to the objects. The data from the four familiarization trials suggest that this is not the case. We compared the looking times on the labeled familiarization trials with the silent ones, for both the two-word and the one-word conditions. Consistent with earlier findings (Baldwin & Markman, 1989), looking times on the labeled trials were longer than those on the silent trials. However, the extent to which looking time had increased was the same in the two-word and the one-word conditions. Thus the presence of labels heightened the infants’ attention equally whether they heard one or two words. But on the test trials, only the infants in the two-word condition succeeded at the task by looking longer at the unexpected, one-object outcome. Therefore a simple account on which words increase attention is unlikely to be correct.

In the second experiment, using a different pair of objects (a cup and a shoe), we contrasted two words with two distinct tones. The procedure was otherwise identical to the first experiment. The question was whether any auditory cues would facilitate performance on this task. The results showed that the infants looked longer at the

one-object, unexpected outcome when they heard two words but they looked longer at the two-object, expected outcome when they heard two tones. These studies provide some initial evidence that words may have a privileged role in picking out object kinds for the infant even at the very beginning of language acquisition.

To further support the idea that language may play an important role in identifying kinds of objects, recent studies by Simons (1996), reviewed above, found that even for adults, verbal labeling may be crucial for the identification of objects.

4.3. What is the role of language and how do we integrate the two parts of the conjecture?

The studies reviewed above suggest strongly that language plays some role in our representations of kinds of objects. What specifically is the role of language, and how does this part of the conjecture fit with the hypothesized maturational changes?

I put forth two possibilities, both rather speculative given the state of the existing evidence. Both possibilities depend on the assumption that different words (e.g., dog, cat, cup, ball) pick out distinct kinds of things and that these kinds (or categories) are mutually exclusive. This assumption is, however, independently motivated by research on word learning. Markman and her colleagues demonstrated that young children may come to the word learning task with the expectation that words for objects pick out categories which are mutually exclusive (Markman, 1989).

How does this assumption help? The first possibility is that the maturational changes take place largely unaffected by other factors aside from the minimal requirements on nutrition for the organism. The “what” and “where” pathways develop independently early on; they become integrated (probably in the pre-frontal cortex, see Rao et al., 1997, reviewed above) at the end of the first year. Once the “what” information and the “where” information are integrated, a further step has to be taken to set the criteria for object individuation. That is, which property changes should be included in computing the number of objects? After all, some objects change shapes (e.g., a hand in a fist or an open palm) and sizes (e.g., plants grow) but remain the same individual. Language could play the role of giving the child signals to different kinds. If two objects are labeled with two different words, they must belong to different kinds, so they must be two distinct objects as well. Thus hearing an object being called “a cup” and another object, seen on a different occasion, being called “a ball” would lead the child to conclude that these are two different kinds of objects.

The second (and much more radical) possibility is to entertain a quite different role for language, inspired by Elizabeth Spelke (personal communication). Hermer and Spelke (1997) argued that humans and non-human primates share a set of largely encapsulated and task-specific modules due to our evolutionary history. Some examples are a geometric module for representing the layout of our immediate environment, a module for computing people’s intentions, and a module for representing objects. The hypothesized role of language, on this view, is to allow humans to “conjoin” these largely encapsulated and task-specific representations. For example, Hermer and Spelke found that 2-year-old children, like rats, rely

exclusively on the geometric shape of the environment to reorient themselves. That is, if asked to search for a hidden toy in a rectangular room after being spun around several times, they go to the two geometrically equivalent corners 100% of the time, splitting equally between the two places. This makes sense given that all the walls are white and the two corners are geometrically equivalent. Surprisingly, the search behavior remains the same even when one of the walls is painted bright blue, thus providing the cue for identifying a unique corner as the location of the hidden object. Preliminary results also suggest that it is not until children acquire prepositional phrases such as “left of the blue wall” that they succeed in this task. Hermer and Spelke suggest that rats and human infants are born with an encapsulated geometric module which only represents the geometric layout of an environment without further specification of landmarks or features. Rats and human babies are also born with a module for encoding object properties such as the color of the wall. However, humans, but not rats, ultimately conjoin these two representations, allowing us to represent “left of the blue wall.” What gives us this more powerful computational system? Their answer is: language. Language, being a combinatorial computational system, conjoins these representations to make more complex thoughts possible.

We could take this idea a step further, applying it at the lexical level. Human infants as well as non-human primates both possess two visual pathways, the “what” and the “where” systems. Language allows the infant to conjoin these two types of representations. When a child hears a word which refers to an object (e.g., “Look, a cup”), she may have certain assumptions about how words for objects should behave. Two word learning constraints proposed by Markman (1989) are relevant: the whole object constraint and the taxonomic constraint. The whole object constraint says that the learner assumes that words refer to whole objects as opposed to parts of objects or colors of objects. The taxonomic constraint says that the learner assumes that words refer to kinds of objects (e.g., a poodle and a golden retriever) but not just any group of objects that are associated with each other (e.g., a dog and its bone). When a child hears a word that refers to an object, these constraints have to be satisfied. That is, each word should refer to whole objects which share a certain set of properties. Conveniently, the “where” system provides the whole objects needed to satisfy the whole object constraint and the “what” system provides the object property information needed to satisfy the taxonomic constraint. So the process of word learning is also a process of integrating the “what” and the “where” information.

An immediate concern arises since clearly non-human primates can and do integrate the “what” and the “where” information (e.g., Rao et al., 1997, reviewed above). It is possible that by virtue of being pre-linguistic, as opposed to being ailinguistic like non-human primates, human infants simply possess a different mechanism for integrating these two types of information, namely language.

The study of the mechanism of change has just begun. Many questions remain open, and much empirical work is needed to further our understanding of the mechanism which underlies the developmental change between 10 and 12 months of age.

5. Concluding remarks

I have attempted to provide a general framework for understanding object individuation and object identity in infancy. The proposal tries to bring together two fields – object perception and cognition in infancy and object-based attention in adults – in order to provide an account of the empirical results. In my view, cognitive developmental psychologists may benefit a great deal from theories of cognitive processes in adults. After all, one major goal of the study of cognitive development is to discover what parts of our cognitive architecture are innate and how infants become adults.

This line of research also speaks to how the acquisition of language may impact children's conceptual representations. I am not the first to argue that perhaps the process of language learning is also a process of conceptual change, but with further empirical studies, we hope to provide a more detailed account of how language and cognition may interact in cognitive development.

Acknowledgements

This research was supported by a Northeastern University faculty grant and a B/START grant from NIH to the author. I thank Susan Carey, Marc Hauser, Alan Leslie, Brian Scholl, Cristina Sorrentino, Elizabeth Spelke, and Joshua Tenenbaum for helpful discussion. Special thanks to John Hummel, Jeannine Pinto, and Cristina Sorrentino for detailed comments on earlier drafts of the paper.

References

- Atkinson, J. (1993). A neurobiological approach to the development of 'where' and 'what' systems for spatial representation in human infants. In N. Eilan, R. McCarthy & B. Brewer Eds. *Spatial representation: Problems in philosophy and psychology* (pp. 325–339). Oxford, UK: Blackwell.
- Baillargeon, R. (1994). How do infants learn about the physical world. *Current Directions in Psychological Science*, 3, 133–140.
- Baillargeon, R. (1995). A model of physical reasoning in infancy. In C. Rovee-Collier & L. P. Lipsitt Eds. *Advances in infancy research* (Vol. 9, pp. 305–371). Norwood, NJ: Ablex.
- Balaban, M., & Waxman, S. (1996). Words may facilitate categorization in 9-month-old infants. *Journal of Experimental Child Psychology*, 64, 3–26.
- Baldwin, D., & Markman, E. (1989). Establishing word-object relations: A first step. *Child Development*, 60, 381–398.
- Bogartz, R., Shinsky, J., & Speaker, C. (1997). Interpreting infant looking: The event set x event set design. *Developmental Psychology*, 33, 408–422.
- Bower, T. G. R. (1974). *Development in infancy*. San Francisco, CA: W.H. Freeman.
- Cohen, L. B., & Younger, B. A. (1983). Perceptual categorization in the infant. In E. K. Scholnick, *New trends in conceptual representation* (pp. 197–200). Hillsdale, NJ: Erlbaum.
- Condry, K., Levine, A., & Simons, D. (1999). *Infant perception of the features and locations of objects in spatial arrays*. Poster presented at the Biennial Meeting for the Society for Research in Child Development, Albuquerque, New Mexico.

- Eimas, P., & Quinn, P. (1994). Studies on the formation of perceptually based basic-level categories in young infants. *Child Development*, *65*, 903–917.
- Fantz, R. L. (1964). Visual experience in infants: Decreased attention to familiar patterns relative to novel ones. *Science*, *146*, 668–670.
- Feldman, J. (1999). The role of objects in perceptual grouping. *Acta Psychologica*, *102*, 137–163.
- Geach, P. (1957). *Mental acts*, London, UK: Routledge & Kegan Paul.
- Goodale, M. (1995). The cortical organization of visual perception and visuomotor control. In S. Kosslyn & D. Osherson, *An invitation to cognitive science* (2nd ed.), Visual cognition (Vol. 2, pp. 167–214). Cambridge, MA: MIT Press.
- Gupta, A. (1980). *The logic of common nouns*, New Haven, CT: Yale University Press.
- Hirsch, E. (1982). *The concept of identity*, New York: Oxford University Press.
- Hermer, L., & Spelke, E. S. (1997). Modularity and development: The case of spatial reorientation. *Cognition*, *61*, 195–232.
- Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. In R. Parasuraman & D.R. Davies, *Varieties of attention* (pp. 29–61). New York: Academic Press.
- Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology*, *24*, 174–219.
- Kanwisher, N., & Driver, J. (1992). Objects, attributes, and visual attention: Which, what, and where. *Current Directions in Psychological Science*, *1*, 26–31.
- Kellman, P., & Spelke, E. S. (1983). Perception of partly occluded objects in infancy. *Cognitive Psychology*, *15*, 483–524.
- Leslie, A. M. (1994). ToMM, ToBy, and agency: Core architecture and domain specificity. In L. Hirschfeld & S. Gelman, *Domain-specificity in cognition and culture* (pp. 119–148). New York: Cambridge University Press.
- Leslie, A., Xu, F., Tremoulet, P., & Scholl, B. J. (1998). Indexing and the object concept: Developing what and where systems indexing. *Trends in Cognitive Sciences*, *2*(1), 10–18.
- Macnamara, J. (1987). *A border dispute: The place of logic in psychology*, Cambridge, MA: MIT Press.
- Mandler, J. M., & McDonough, L. (1996). Drinking and driving don't mix: Inductive generalization in infancy. *Cognition*, *59*, 307–335.
- Markman, E. (1989). *Categorization and naming in children*, Cambridge, MA: MIT Press.
- Medin, D. L., & Ortony, A. (1989). Psychological essentialism. In S. Vosniadou & A. Ortony, *Similarity and analogical reasoning* (pp. 189–223). Cambridge, England: Cambridge University Press.
- Munakata, Y., McClelland, J., Johnson, M., & Siegler, R. (1997). Rethinking infant knowledge: Toward an adaptive process account of successes and failures in object permanence tasks. *Psychological Review*, *104*(4), 686–713.
- Needham, A. (1998). Infants' use of featural information in the segregation of stationary objects. *Infant Behavior and Development*, *21*(1), 47–76.
- Needham, A., & Baillargeon, R. (1998). Effects of prior experience on 4.5-month-old infants' object segregation. *Infant Behavior and Development*, *21*(1), 1–24.
- Oakes, L. M., Madole, K., & Cohen, L. B. (1991). Infants' object examining: Habituation and categorization. *Cognitive Development*, *6*, 377–392.
- Park, M., & Xu, F. (1999). *Object individuation in infancy: Integrating what and where information*. Poster presented at the Biennial Meeting for the Society for Research in Child Development, Albuquerque, New Mexico.
- Pylyshyn, Z. W. (1990). The role of location indexes in spatial perception: A sketch of the FINST spatial index model. *Cognition*, *32*, 65–97.
- Quinn, P. C., Eimas, P., & Rosenkrantz, S. L. (1993). Evidence for representations of perceptually similar natural categories by three- and four-month-old infants. *Perception*, *22*, 463–475.
- Rao, S. C., Rainer, G., & Miller, E. (1997). Integration of what and where in the primate prefrontal cortex. *Science*, *276*, 821–824.
- Schneider, G. E. (1969). Two visual systems. *Science*, *163*, 895–902.
- Simons, D. J. (1996). In sight, out of mind: When object representations fail. *Psychological Science*, *7*, 301–305.

- Spelke, E. S. (1985). Preferential looking methods as tools for the study of cognition in infancy. In G. Gottlieb & N. Krasneger, *Measurement of audition and vision in the first year of postnatal life* (pp. 323–363). Norwood, NJ: Ablex.
- Spelke, E. S. (1990). Principles of object perception. *Cognitive Science*, *14*, 29–56.
- Spelke, E. S. (1996). Initial knowledge: Six suggestions. *Cognition*, *50*, 431–445.
- Spelke, E. S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review*, *99*, 605–632.
- Spelke, E. S., Breinlinger, K., Jacobson, K., & Phillips, A. (1993). Gestalt relations and object perception: A developmental study. *Perception*, *22*, 1483–1501.
- Spelke, E. S., Kestenbaum, R., Simons, D., & Wein, D. (1995). Spatiotemporal continuity, smoothness of motion and object identity in infancy. *British Journal of Developmental Psychology*, *13*, 113–142.
- Trick, S., & Pylyshyn, Z. W. (1994). Why are small and large numbers enumerated differently? A limited-capacity preattentive stage in vision. *Psychological Review*, *101*, 80–102.
- Tse, P. (1999). Complete mergeability and amodal completion. *Acta Psychologica*, *102*, 165–201.
- Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. In D. G. Ingle, M. A. Goodale, & R. J. Q. Mansfield, *Analysis of visual behavior* (pp. 549–586). Cambridge, MA: MIT Press.
- Van de Walle, G., Prevor, M., & Carey, S. (under review). The use of kind distinctions for object individuation: Evidence from reaching. Manuscript under review.
- Van Essen, D. C., & Maunsell, J. H. R. (1983). Van Hierarchical organization and functional streams in the visual cortex. *Trends in Neurosciences*, *6*, 370–375.
- Van Lier, R. (1999). Investigating global effects in visual occlusion: From a partly occluded square to the back of a tree-trunk. *Acta Psychologica*, *102*, 203–220.
- Van Hofsten, C., Vishton, P., Spelke, E. S., Feng, Q., & Rosander, K. (1998). Von Predictive action in infancy: Tracking and reaching for moving objects. *Cognition*, *67*, 255–285.
- Waxman, S., & Markow, D. (1996). Words as invitations to form categories: Evidence from 12- to 13-month-old infants. *Cognitive Psychology*, *29*, 257–302.
- Wiggins, D. (1980). *Sameness and substance*, Oxford, England: Basil Blackwell.
- Wilcox, T., & Baillargeon, R. (1998a). Object individuation in infancy: The use of featural information in reasoning about occlusion events. *Cognitive Psychology*, *37*, 97–155.
- Wilcox, T., & Baillargeon, R. (1999). Object individuation in young infants: Further evidence with an event-monitoring paradigm. *Developmental Science*, (in press).
- Xu, F. (1997). From Lot's wife to a pillar of salt: Evidence that *physical object* is a sortal concept. *Mind & Language*, *12*, 365–392.
- Xu, F. (1998). Distinct labels may provide pointers to distinct sortals in nine-month-old infants. In E. Hughes, M. Hughes, & A. Greenhill, *Proceedings of the 22nd Annual Boston University Conference on Language Development* (pp. 791–796). Somerville, MA: Cascadilla Press.
- Xu, F., & Carey, S. (1996). Infants' metaphysics: The case of numerical identity. *Cognitive Psychology*, *30*, 111–153.
- Xu, F., Carey, S., & Quint, N. (in preparation). Object individuation at 12 months: Shape and other properties. Manuscript in preparation.
- Xu, F., Carey, S., & Welch, J. (in press). Infants' ability to use object kind information for object individuation. *Cognition*.