Chapter 15

Cognitive Capacities of Human Infants: Conceptions of Object Motion

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ABSTRACT

Under certain conditions, human infants apprehend the existence and location of objects that are fully hidden, they determine the identity or distinctness of objects that appear in different places and at different times, and they infer the unseen paths and final positions of objects that have moved out of view. These abilities testify to an early developing recognition of physical constraints on object motion: Infants conceive of objects as movable only through unoccupied space, as movable on spatiotemporally continuous paths and (by the age of six months) as subject to gravity. Human abilities to represent objects and to appreciate constraints on object motion appear to develop rapidly and spontaneously on the basis of limited experience. The existence of these abilities raises questions for students of the nervous system and its growth and organization.

The study of the nervous system is rich and challenging because neuroscientists can gain insights from discoveries within a wide range of disciplines. As many chapters in this volume attest, insights about neural organization can come from studies of elementary neural structures and their interactions and from studies of the emergence and the growth of these structures and interactions. Insights can also come from studies of the behavioral and mental capacities of mature animals. Discoveries within such disciplines as biology, anthropology, psychology, linguistics, and music, for example, can illuminate the tasks performed by the mature human brain.

Finally, insights into the nervous system can come from studies of psychological development. Developmental studies of mind and behavior promise to shed light on the nervous system in at least three ways. First, these studies suggest when the neural structures subserving a given ability begin to function. Second, these studies suggest the conditions under which those neural structures arise. If a given ability is found to develop under a certain set of circumstances, then the nervous system itself must grow in such a way that the structures subserving that ability emerge under the same circumstances. Third, studies of psychological development suggest how mental life, and its physical basis, are structured. At any given time, a developing organism will exhibit a constellation of abilities that both resembles, and differs from, that of adults. A consideration of these commonalities and differences can shed light on the organization of psychological capacities at all ages.

The present chapter focuses on one aspect of early cognitive development: young infants' inferences about the unseen states and behaviors of physical objects. I consider three interrelated mental abilities: the ability to infer the continuous existence of an object that is fully hidden, the ability to establish the identity of an object that appears and disappears at different places and times, and the ability to infer the future motions and positions of an object that moves while fully out of view. To convey a sense of the enterprise of studying cognition in human infancy, I discuss a small number of experiments in some detail. I hope, however, that this discussion will serve to illustrate three more general suggestions.

The first suggestion concerns the time of onset of cognitive functioning. Some important cognitive abilities, such as the ability to evoke an object in its absence, arise early in life and develop in parallel with abilities to perceive and to act. The second suggestion concerns the conditions under which cognition emerges. Some cognitive abilities arise on the basis of limited perceptual or motor experience, and they continue to develop in the absence of instruction or special interventions by other humans. The third suggestion concerns the organization of cognitive abilities. Much of cognition may depend not on general-purpose learning mechanisms but on special-purpose mechanisms for representing and learning about entities of particular kinds. These suggestions pose what I hope will be a fruitful challenge to students of neuroscience: the challenge of discovering nervous system structures that underlie cognitive performance in particular domains of knowledge, which begin to emerge early in development and which grow rapidly and spontaneously in creatures who observe the world around them, but who are largely incapable of acting on the world or communicating about it.

A METHOD FOR STUDYING COGNITION IN INFANCY

Philosophers and scientists have speculated about the development of human cognition for millennia, but experimental studies of cognition in infancy have begun to be productive only in the last decades. The reasons for this delay are not difficult to discern: Human infants have extremely limited abilities to act and to communicate, and these limitations pose special problems for any scientist who would study what humans perceive and understand at the beginning of life. Whereas students of mature human cognition can question their subjects about their perceptions or thoughts, and whereas students of animal cognition can observe the intricate behavior patterns of insects, birds, or mammals who find their way home, search for food, and recognize predators or conspecifics, students of human infancy have neither of these options. How can one investigate infants' capacities to perceive and to reason?

Much of the recent research on infant perception and cognition began with a simple discovery: Although young infants are largely incapable of acting so as to change the world or communicate about it, they are quite capable of acting so as to observe and to learn. From birth, infants look at objects systematically, they listen to objects by quieting and turning their eyes or heads in the appropriate direction, and they grasp and hold objects that are placed in their hands (Gibson and Spelke, 1983). In all these cases, infants come to recognize that which they explore (Olson and Sherman, 1983). If infants are presented with the same object repeatedly, their

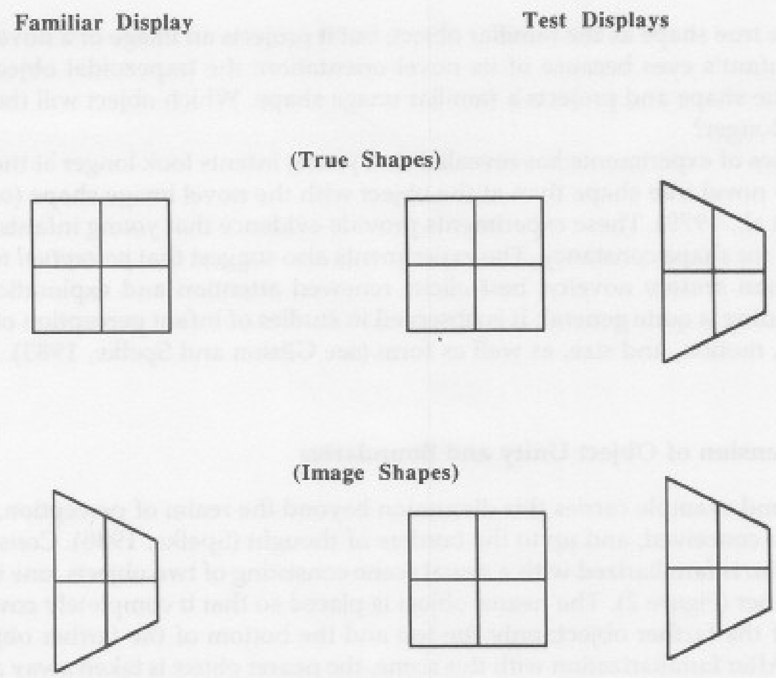

Figure 1. *Displays for an experiment on shape perception in infancy.*

exploration of the object declines over time. If they are then presented with a new object, their exploration increases [for examples of this phenomenon in different sensory modes, see Spelke, 1985 (vision); Schneider and Trehub, 1985 (audition); and Streri, 1987 (touch)]. This *reaction to novelty* reveals that infants have registered and remembered the first object, and that they distinguish it from the second object.

Infants' pervasive orientation toward novelty is observed from the day of birth to the onset of language, or beyond. It has provided psychologists with a method for studying a wide range of psychological capacities from sensory discrimination (see Banks and Salapatek, 1983) to memory (see Olson and Sherman, 1983) and categorization (see Eimas and Miller, this volume). In the studies discussed in this chapter, infants' reactions to novelty are used to investigate what infants perceive and understand about the world around them. Novelty reactions can be used to study such perceptual and cognitive capacities because of a striking phenomenon these studies have revealed. In a wide range of situations, infants respond most strongly to novelty in the world as it is perceived or conceived, rather than to novelty in an immediate pattern of stimulation. Two examples serve to illustrate this phenomenon.

Perception of Object Form

Consider an infant who is familiarized with a rectangular object at an oblique orientation and then is tested with two objects at a frontal orientation: a rectangular object of the same real shape and a trapezoidal object (Figure 1). Each of these objects is familiar in one respect and novel in another: The rectangular object has the same true shape as the familiar object, but it projects an image of a novel shape to the infant's eyes because of its novel orientation; the trapezoidal object has a novel true shape and projects a familiar image shape. Which object will the infant explore longer?

A series of experiments has revealed that young infants look longer at the object with the novel true shape than at the object with the novel image shape (see, e.g., Caron et al., 1979). These experiments provide evidence that young infants have a capacity for shape constancy. The experiments also suggest that *perceptual* novelty, rather than *sensory* novelty, best elicits renewed attention and exploration. The latter finding is quite general: It is observed in studies of infant perception of object position, motion, and size, as well as form (see Gibson and Spelke, 1983).

Apprehension of Object Unity and Boundaries

The second example carries this discussion beyond the realm of perception, as it is narrowly conceived, and up to the borders of thought (Spelke, 1988). Consider an infant who is familiarized with a visual scene consisting of two objects, one in front of the other (Figure 2). The nearer object is placed so that it completely covers the center of the farther object; only the top and the bottom of the farther object are visible. After familiarization with this scene, the nearer object is taken away and the infant is presented with two displays, one consisting just of the pieces of the farther object that were visible in the initial scene, and the other consisting of the complete physical body that adults would consider to be present in that scene. Which test display will the infant look at longer: the one that corresponds to the surfaces he or she has observed, or the one that corresponds to the complete object?

The answer to this question is a bit complex, for it depends on whether the original display was presented in motion (for details, see Spelke, 1988). During scores of studies, however, only two reactions have been observed. First, if the center-occluded object underwent a rigid three-dimensional displacement, infants of four months (the youngest age tested) looked longer at the visible pieces of the object. They treated the complete object as a familiar display, even though it presented surfaces they had not seen before. Second, if the original center-occluded object was stationary, or if it moved with its occluder, infants showed increased looking at both test displays. In this situation, infants appeared not to know whether the complete object in the test was the same as the object in the familiar scene, and thus they reacted to both test displays as novel. Infants have never shown a third, logically possible response: In no experiment have they generalized from a partly hidden object to a display with the same configuration of visible surfaces.

Analogous findings have been obtained in experiments in which four-month-old infants feel objects instead of looking at them (Streri and Spelke, 1988). Infants were allowed to hold the two ends of a rigid object, one end in each hand, on a series of familiarization trials (Figure 3). They could not feel the center of this object, but they could move the two ends they held; when they did this, the ends moved rigidly together. Then they were presented with two visual displays: a display consisting just of the object ends they had touched and a display consisting of a complete, rigid object. Infants looked longer at the object pieces. They treated the

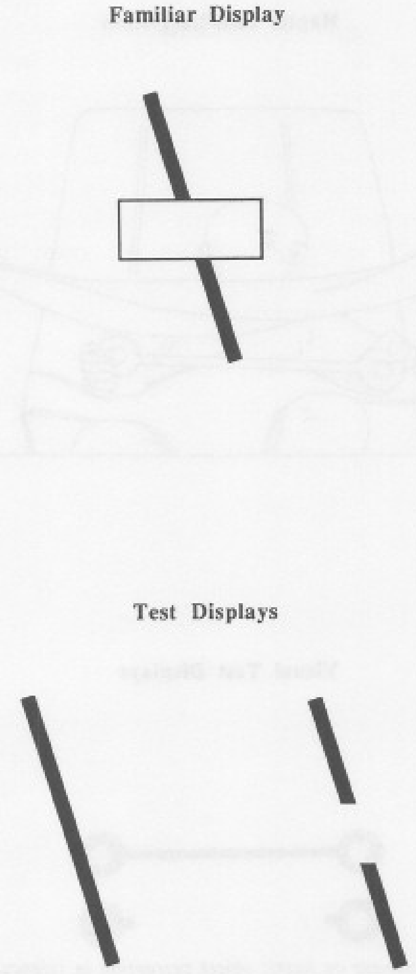

Figure 2. *Displays for an experiment on infants' perception of partly hidden objects.* (From Kellman and Spelke, 1983.)

complete object as familiar, despite the fact that much of the object had never been contacted directly during the familiarization period.

These studies provide evidence that infants can perceive complete objects from partial visual or tactile information. In addition, the experiments show that infants treat a display as novel if the display appears to contain a new object, whether or not the display contains newly visible or tangible object surfaces. Like adults, infants are oriented to novelty in the world as they perceive or understand it, not to novelty in their more immediate visual or tactile impressions.

In recent years, the study of infants' orientation to novelty has been pushed further in two respects. First, experiments have investigated whether infants exhibit novelty reactions to situations in which they are presented with familiar objects whose behavior violates physical constraints on object motion. Second, experiments have investigated whether infants exhibit novelty reactions to object behav-

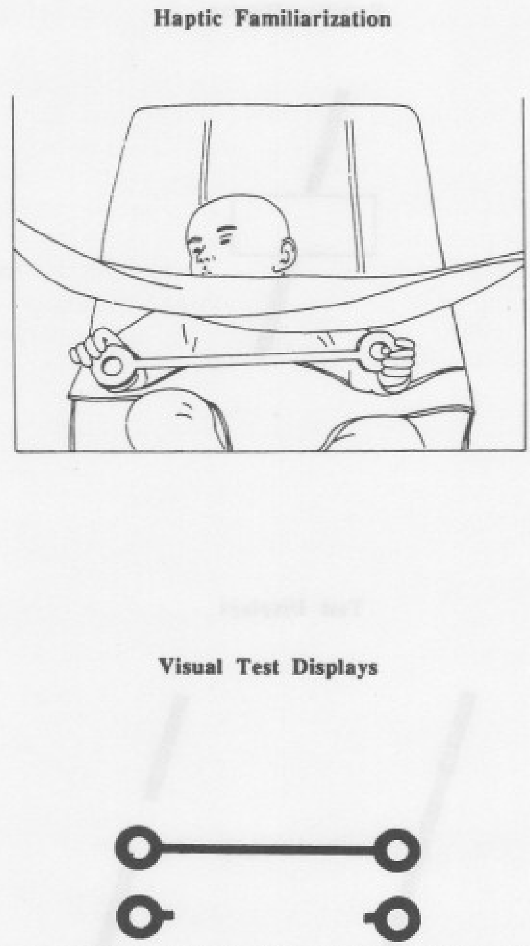

Figure 3. *Displays for an experiment on haptic object perception in infancy.* (From Streri and Spelke, 1988.)

iors they cannot see directly because the relevant behavior occurs while the object is fully hidden. These studies provide evidence concerning infants' abilities to represent hidden objects, to establish relations of identity and distinctness among objects that appear at different places and times, and to infer how hidden objects move and where they come to rest. The rest of this chapter focuses on these abilities.

APPREHENDING THE EXISTENCE OF A HIDDEN, STATIONARY OBJECT

As adults, we infer that objects continue to exist when we no longer see them. This inference reflects the fundamental notion that the world is independent of our acts of perception: We do not create or destroy the world by opening or closing our eyes but observe a world that exists continuously (Piaget, 1954). Do infants make similar inferences, apprehending objects as continuing to exist when they are hidden from view? This question has been addressed through experiments that focus on a simple situation in which a stationary object disappears behind a moving screen.

In the first study (Baillargeon et al., 1985), five-month-old infants were familiarized with a screen that rotated 180° on a surface (Figure 4). Then the infants were shown a block standing fully in view behind the screen, which rested on the surface. Finally, the infants were tested with two events in which the screen rotated upward, fully occluding the block. In one event, the screen reversed direction when it reached the place the hidden block occupied. This motion was novel (120° rather than 180° of rotation) but possible. In the other event, the screen rotated the full 180° before reversing direction. This motion was familiar but was judged by adults to be impossible because it carried the screen through the place the hidden block had occupied. The impossibility of the 180° test event follows from the notion that a stationary object continues to exist in a constant location while hidden.

The infants in this study looked longer at the familiar but impossible motion than at the novel but possible motion (Figure 5). This reaction was not observed when infants were presented with events in which the block stood beside the screen and out of its path, such that both events were possible. Infants responded with heightened exploration to the 180° test rotation only when the rotation carried the screen through the position occupied by the hidden object. The experiment therefore provides evidence that infants apprehended the continued existence of the block.

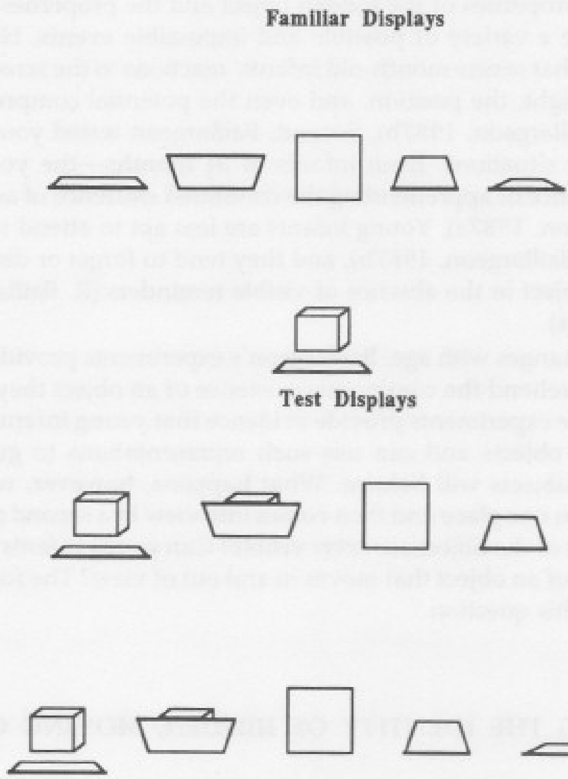

Figure 4. *Displays for an experiment on infants' apprehension of the continuous existence of a hidden object.* (From Baillargeon et al., 1985.)

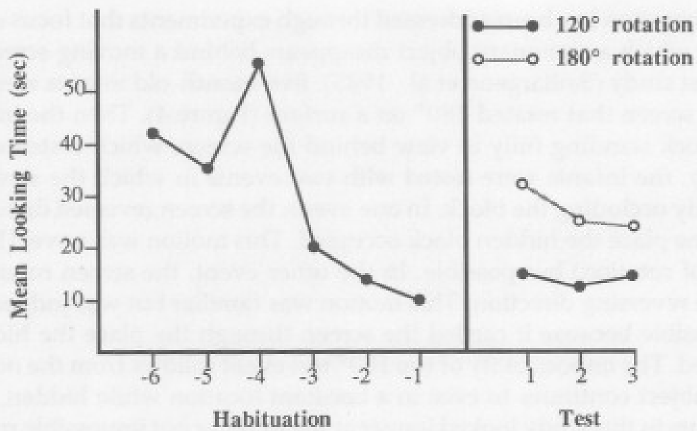

Figure 5. *Looking times during the last six familiarization trials and the six test trials of an experiment on 5½-month-old infants' apprehension of the continuous existence of a hidden object.* (Adapted from Baillargeon et al., 1985.)

In subsequent research, Baillargeon has extended this finding in several directions. First, she studied the properties of hidden objects represented by infants, by varying both the properties of the hidden object and the properties of the screen's motion to produce a variety of possible and impossible events. Her experiments provide evidence that seven-month-old infants' reactions to the screen's motion are affected by the height, the position, and even the potential compressibility of the hidden object (Baillargeon, 1987b). Second, Baillargeon tested younger infants in some of the same situations. Even infants of 3½ months—the youngest age yet tested—give evidence of apprehending the continued existence of an object behind a screen (Baillargeon, 1987a). Young infants are less apt to attend to the occlusion events, however (Baillargeon, 1987b), and they tend to forget or disregard properties of a hidden object in the absence of visible reminders (R. Baillargeon, unpublished observations).

Despite these changes with age, Baillargeon's experiments provide evidence that young infants apprehend the continuous existence of an object they no longer see. More generally, the experiments provide evidence that young infants can represent previously visible objects and can use such representations to guide inferences about how other objects will behave. What happens, however, when a moving object disappears in one place and then comes into view in a second place, such that intermediate states of the object are *never* visible? Can young infants apprehend the persisting identity of an object that moves in and out of view? The following experiments addressed this question.

APPREHENDING THE IDENTITY OF HIDDEN, MOVING OBJECTS

Adults have the ability to identify objects over time, determining whether an object that is currently in view is the same as, or distinct from, some object seen in the past.

The capacity to apprehend object identity is central to our mature conception of the world, and its origins have long been a subject of speculation (see Quine, 1960). Recent experiments have attempted to study those origins by means of the reaction-to-novelty method.

Infants' apprehension of object identity was first investigated in two situations involving one object or two featurally identical objects that moved behind two spatially separated screens (Spelke and Kestenbaum, 1986) (Figure 6). In one event, the object motion behind the screens was continuous; in the other event, the motion was discontinuous: No object appeared between the screens. Although the events were otherwise the same (in particular, each event presented only a single object at any given time), adults described them differently: The continuous event was said to involve one object, whereas the discontinuous event was said to involve two objects. These descriptions follow from a physical constraint on object motion: Objects only move on connected paths.

Separate groups of four-month-old infants were familiarized with the continuous event, the discontinuous event, and no event (a baseline control), and then all

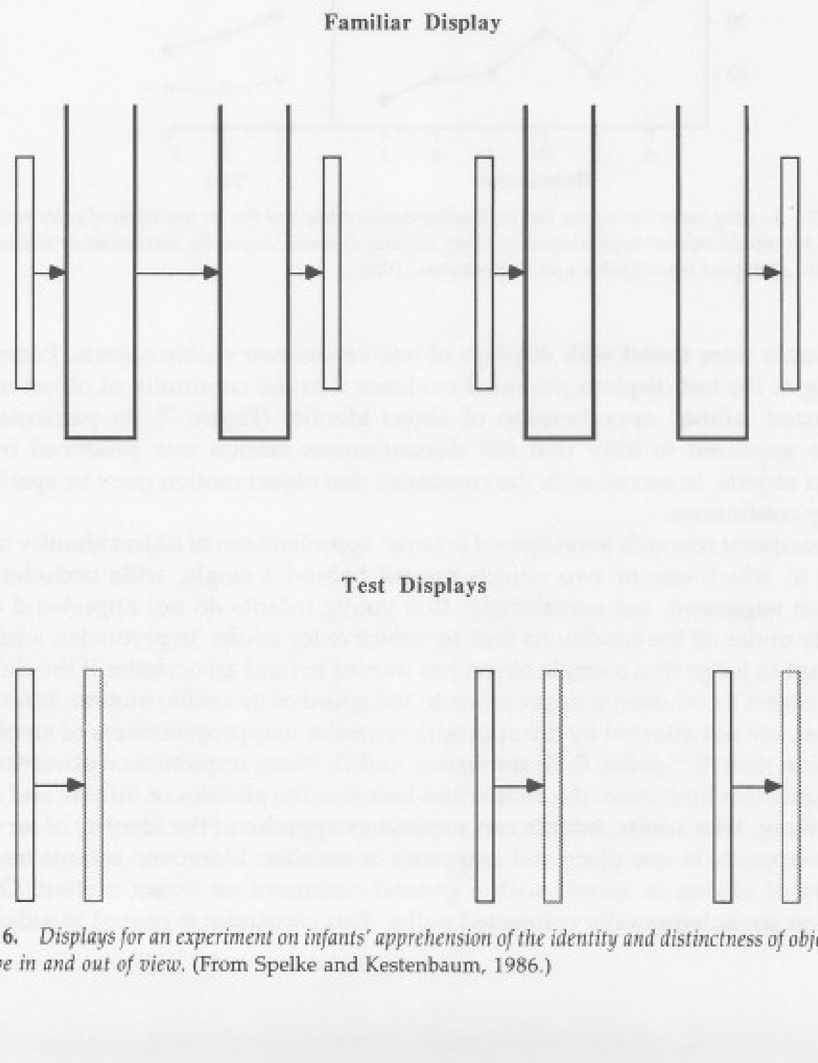

Figure 6. *Displays for an experiment on infants' apprehension of the identity and distinctness of objects that move in and out of view.* (From Spelke and Kestenbaum, 1986.)

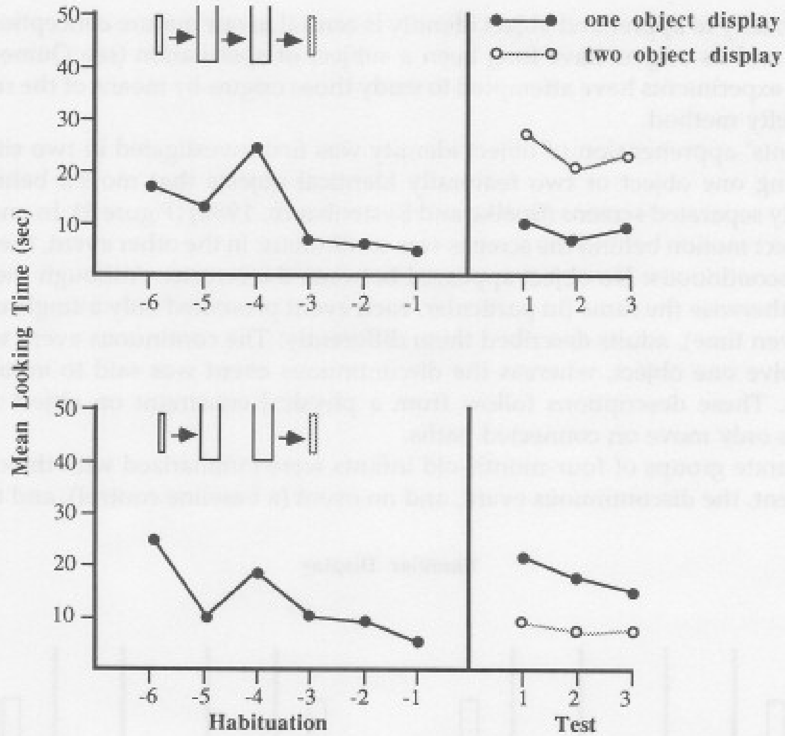

Figure 7. *Looking times during the last six familiarization trials and the six test trials of an experiment on four-month-old infants' apprehension of object identity in spatiotemporally continuous or discontinuous events.* (Adapted from Spelke and Kestenbaum, 1986.)

the infants were tested with displays of one versus two visible objects. Patterns of looking at the test displays provided evidence that the continuity of object motion influenced infants' apprehension of object identity (Figure 7). In particular, the infants appeared to infer that the discontinuous motion was produced by two distinct objects, in accord with the constraint that object motion must be spatiotemporally continuous.

Subsequent research investigated infants' apprehension of object identity in situations in which one or two objects moved behind a single, wide occluder. This research suggested, not surprisingly, that young infants do not apprehend object identity under all the conditions that are effective for adults. In particular, adults are more apt to judge that a single object has moved behind an occluder if the duration of the object's occlusion is appropriate to the speed of its visible motion. Infants, by contrast, are not affected by the appropriateness or inappropriateness of an object's occlusion time (E. Spelke, R. Kestenbaum, and D. Wein, unpublished observations).

Despite this limitation, the similarities between the abilities of infants and adults are striking. Like adults, infants can sometimes apprehend the identity of an object that disappears in one place and reappears in another. Moreover, infants trace the identity of objects in accord with a general constraint on object motion: Objects move on spatiotemporally connected paths. This constraint is central to judgments about object identity that mature humans make (Hirsch, 1982). Early physical conceptions and mature physical conceptions do not appear to differ as radically as has sometimes been supposed (see, e.g., Piaget, 1954; Quine, 1960).

INFERRING THE FINAL POSITION OF AN OBJECT THAT MOVES FROM VIEW

Let us turn to situations in which an object moves out of view and remains hidden. Adults often can infer how such an object will continue to move and where it will come to rest. For example, consider an event in which a ball rolls out of sight on a table. If a second hidden object stands in the ball's path, an adult will infer that one or the other object will give way: The ball will not jump over or pass through the second object. This inference follows from two constraints on object motion: the continuity constraint, already discussed, and the solidity constraint whereby two bodies cannot occupy the same place at the same time. If the ball arrives at the edge of the table, an adult will infer that the ball will begin to move downward. This prediction follows from a third constraint on object motion: Objects are subject to gravity.

We have recently begun to investigate whether young infants make similar inferences in accord with these constraints. The first study (Macomber et al., 1988) investigated whether four-month-old infants expect that hidden objects will not jump over or pass through each other. On a series of familiarization trials, infants viewed an open stage. A screen was lowered over the center of the stage, a ball was introduced above the screen and dropped behind it, and finally the screen was raised to reveal the ball in the position adults expect it to occupy: the stage floor (Figure 8). After these trials, a second horizontal surface was placed above the first surface. The screen was lowered, the ball was introduced and dropped behind it, and the screen was raised to reveal the stationary ball in one of two positions. On half the test trials, the ball appeared in the familiar position. This position violates the continuity and solidity constraints, since the ball could reach the familiar position only by jumping over or passing through the new surface. On the other trials, the ball appeared on the new surface, a position that is novel but consistent with these constraints on object motion.

Looking time was measured only during the final phase of each of these events, after the screen was raised to reveal the final position of the ball. These looking times were compared to the looking times of infants in a separate control experiment who saw events with the same final configuration of surfaces and objects, all of which were consistent with the spatiotemporal continuity and solidity constraints.

The infants in the principal experiment looked longer when the ball was revealed in the familiar but unexpected position than when it was revealed in the novel but expected position; the infants in the control experiment showed no such preference (Figure 9). This experiment provides evidence that four-month-old infants infer that a hidden, moving object will not pass through or jump over a hidden surface in its path, in accord with the solidity and continuity constraints. Six-month-old infants have been shown to make this inference as well (Baillargeon, 1986).

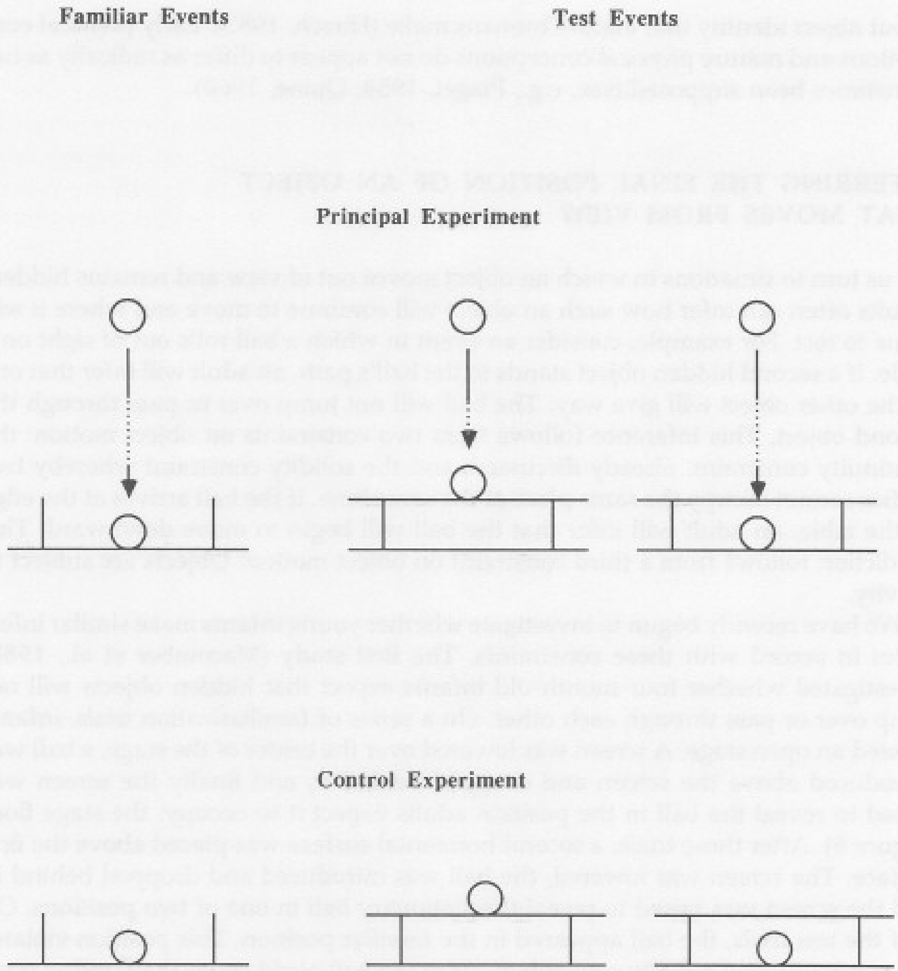

Figure 8. *Displays for an experiment on infants' inferences about the motion of a hidden object with a second hidden object in its path. The object's visible and invisible displacements are indicated by solid and dotted lines, respectively.* (From Macomber et al., 1988.)

Subsequent experiments provide evidence that young infants' inferences about occluded object motion are not guided by all the physical constraints that adults recognize. In particular, four-month-old infants do not appear to infer a hidden object's final position in accord with constraints imposed by gravity (Macomber et al., 1988). Infants were repeatedly shown an object that was dropped behind a screen and revealed to have landed on a surface. Then the surface was removed, the object was dropped behind the screen, and the screen was raised to reveal the object either in its familiar position—now without support—or in a new position on a lower supporting surface. Adults judged the first position to be surprising and the second to be expected, in accord with the gravity constraint. The looking times of six-month-old infants provided evidence that they also adhere to the gravity constraint: They looked longer at the familiar but unexpected position. Four-month-old infants, in contrast, looked longer at the superficially novel position. The younger infants appeared to expect the object to land where it had landed before, independent of the force of gravity.

These last findings provide evidence that knowledge of at least one property of object motion develops after four months of age. Four-month-old infants nevertheless appear to appreciate certain constraints on object motion, and they use those constraints to infer how an object moves after it leaves their view. In the present situation, young infants inferred where a falling object would land even though they had witnessed only the beginning of its descent and had never seen it come to rest. Like adults, young infants gain knowledge that goes far beyond their immediate encounters with objects and events.

CONCLUSIONS AND SUGGESTIONS

Cognition in Infancy

These experiments provide evidence that certain cognitive abilities arise early in human life. Young infants apprehend the existence of an object they no longer see and on which they have never acted. They sometimes can trace the identity of an object that comes into view in different places and at different times, apprehending the object as a single, persisting entity over a series of perceptual encounters. Finally, they sometimes can infer where an object has come to rest when it moves from view at one place and continues moving to another place.

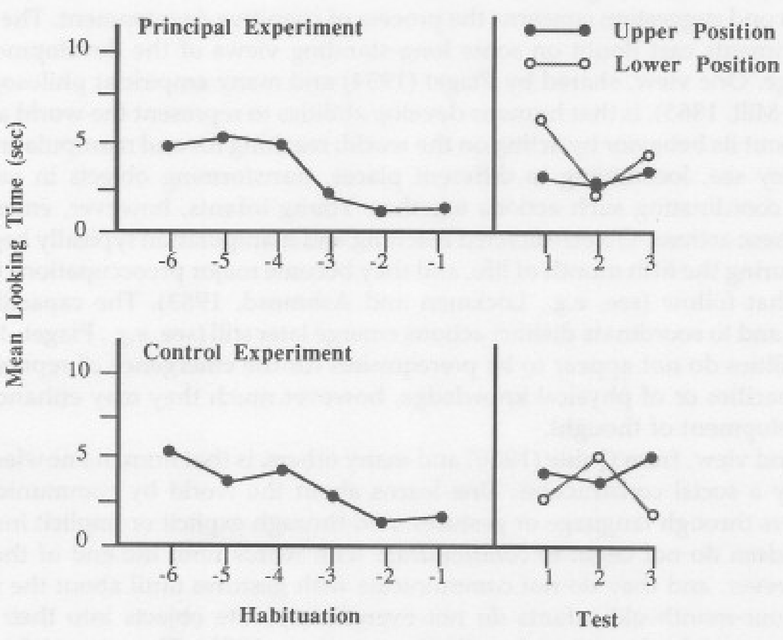

Figure 9. *Looking times during the last six familiarization trials and the six test trials of an experiment on four-month-old infants' inferences about the motion of a hidden object with a second hidden object in its path.* (Adapted from Macomber et al., 1988.)

These abilities testify to an early developing appreciation of physical constraints on the behavior of objects. Four-month-old infants appear to recognize that objects exist when they are out of view, that objects move on connected paths in space and time, and that objects move only through places not currently occupied by other objects. Six-month-old infants (but not four-month-olds) appear to appreciate that objects tend to move in relation to gravity, such that a freely falling object will continue falling until it arrives at a surface of support. Human infants resemble their elders in these respects: Adults, too, apprehend the persistence, the identity, and the positions of hidden objects in accord with physical constraints on object motion. However much human conceptions of objects may grow and change after infancy, certain notions appear to be constant.

Cognition and Cognitive Development

The present findings support several general suggestions about the nature and development of cognitive capacities. One suggestion concerns the time of emergence of cognitive functioning. The capacity to represent the world appears to arise early in infancy and to develop concurrently with the capacities to perceive and to act. Psychological development does not appear to proceed from the periphery inward, with sensory and motor systems maturing before central systems. Instead, cognition appears to be as well rooted in human beings (and perhaps in other organisms: see Gallistel, 1989) as are perception and action. If that is the case, then early developing cognitive capacities will be available to influence the development of perception and action as much as early perceptual and motor capacities influence the development of thought.

The second suggestion concerns the process of cognitive development. The present experiments cast doubt on some long-standing views of the development of knowledge. One view, shared by Piaget (1954) and many empiricist philosophers (see, e.g., Mill, 1865), is that humans develop abilities to represent the world and to reason about its behavior by acting on the world: reaching for and manipulating the things they see, locomoting to different places, transforming objects in various ways, or coordinating such actions together. Young infants, however, engage in none of these actions. Object-directed reaching and manipulation typically begin to emerge during the fifth month of life, and they become major preoccupations in the months that follow (see, e.g., Lockman and Ashmead, 1983). The capacities to locomote and to coordinate distinct actions emerge later still (see, e.g., Piaget, 1954). These abilities do not appear to be prerequisites for the emergence of representational capacities or of physical knowledge, however much they may enhance the later development of thought.

A second view, from Quine (1960) and many others, is that human knowledge is essentially a social construction: One learns about the world by communicating with others through language or gestures, and through explicit or implicit instruction. Children do not begin to communicate with words until the end of the first year, however, and they do not communicate with gestures until about the ninth month. Four-month-old infants do not even incorporate objects into their rich, face-to-face social interactions (see Bretherton et al., 1981). The present findings therefore suggest that the abilities to represent objects and to reason about their behavior begin to develop independently of social communication. Society may enrich or modify preexisting cognitive capacities, but it does not appear to create such capacities *de novo*.

More positively, the present findings suggest that humans first develop knowledge by observing the world, indeed, through observations that are limited both in number and in scope. If that is the case, then the development of knowledge would appear to be guided by internal constraints, permitting rich inductions from limited evidence (see, e.g., Chomsky, 1975). The structure humans find in the world may ultimately be rooted in intrinsic, spontaneously developing mechanisms for representing the world and reasoning about it.

The third suggestion concerns the organization of cognitive capacities. The physical constraints that govern the behavior of objects for human infants—continuity, solidity, and gravity—are *domain specific*. These constraints do not apply to entities in other cognitive domains, such as numbers, geometric forms, or social institutions. Each of the latter kinds of entities behaves in accord with constraints of its own, some of which are grasped quite early in life [for examples of research on early cognitive development in domains other than physics, see Gelman and Gallistel, 1978 (number); Landau et al., 1981 (geometry); and Wellman, 1985 (psychology)]. As early as humans begin to think, they appear to think about different things in different ways.

These considerations suggest that "thinking" is not one unitary activity but a collection of different activities, each applied to representations of a distinct kind of entity and each operating in accord with distinct principles. The mechanisms subserving these activities may be largely autonomous: They may be "modular" in structure (Fodor, 1983; Gallistel, 1989). The modular character of thought may be obscured for adults because of the apparent unity of the conscious experience of thinking. Nevertheless, conscious thought may be the product of a population of distinct mechanisms. Thought may resemble perception in this respect, for perception also depends on a host of semiautonomous mechanisms (see, e.g., Marr, 1982), despite the unity of perceptual experience (see, e.g., Gibson, 1979).

Cognition and the Brain

These suggestions serve as invitations to neuroscientists. First, they invite neuroscientists to look for separable systems in the brain that function to represent entities within particular cognitive domains (intuitive physics, number, geometry) and that serve as a basis for reasoning about those entities and their behavior. Research on early cognitive development casts doubt on the view that the human brain consists of well-defined sensory and motor structures and largely undefined "association areas" in which thinking arises. That view would be plausible if perception and action were innately structured and if thinking were built, in an unconstrained fashion, on their foundations. It is less plausible if cognition, like perception, depends on a collection of separable capacities that begin to emerge early in life and that develop in accord with internal constraints.

Second, these suggestions invite neuroscientists to investigate processes of development that can occur autonomously in the absence of instruction or motor feedback. Research on infancy suggests that cognitive mechanisms begin to develop without guidance from other people and without trial-and-error learning from the child's own actions. Cognitive mechanisms appear to arise and grow either through processes that are independent of specific experiences or through processes that are guided by the infant's limited observations of the world. In either case, their growth would appear to be largely under endogenous control.

Finally, research on infancy invites neuroscientists to consider physical mechanisms that could serve to *represent* the world, evoking unseen objects and supporting inferences about their behavior. Simple introspection indicates that such mechanisms must exist in human adults. Research with infants suggests, however, that these mechanisms are not the specialized achievements of mature, highly experienced humans; they are part of the human nervous system at or near the beginning of life. As infants, humans already go beyond what is immediately perceivable to represent parts of objects that cannot be seen or felt, to represent objects that have been fully removed from view, and to infer object motions and positions that were never seen directly. I would hope such findings will stimulate neuroscientists to study the physical mechanisms that accomplish these tasks, their structure, and their growth.

REFERENCES

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

Baillargeon, R. (1987a) Object permanence in 3.5- and 4.5-month-old infants. *Dev. Psychol.* **23**:655–664.

Baillargeon, R. (1987b) Young infants' reasoning about the physical and spatial characteristics of a hidden object. *Cog. Dev.* **2**:179–200.

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

Banks, M. S., and P. Salapatek (1983) Infant visual perception. In *Handbook of Child Psychology* (formerly *Carmichael's Manual of Child Psychology*), Vol. 2, *Infancy and Developmental Psychology*, M. M. Haith and J. Campos, eds., pp. 435–472, Wiley, New York.

Bretherton, C., S. McNew, and M. Beeghly-Smith (1981) Early person knowledge as expressed in gestural and verbal communication: When do infants acquire a "theory of mind"? In *Infant Social Cognition: Empirical and Theoretical Considerations*, M. E. Lamb and L. R. Sherrod, eds., Erlbaum, Hillsdale, New Jersey.

Caron, A. J., R. F. Caron, and V. R. Carlson (1979) Infant perception of the invariant shape of an object varying in slant. *Child Dev.* **50**:716–721.

Chomsky, N. (1975) *Reflections on Language*, Pantheon Books, New York.

Fodor, J. (1983) *The Modularity of Mind*, Bradford Books/MIT Press, Cambridge, Massachusetts.

Gallistel, C. R. (1989) *The Organization of Learning*, Bradford Books/MIT Press, Cambridge, Massachusetts.

Gelman, R., and C. R. Gallistel (1978) *The Child's Understanding of Number*, Harvard Univ. Press, Cambridge, Massachusetts.

Gibson, E. J., and E. S. Spelke (1983) The development of perception. In *Handbook of Child Psychology* (formerly *Carmichael's Manual of Child Psychology*), Vol. 3, *Cognitive Development*, J. H. Flavell and E. Markman, eds., pp. 1–76, Wiley, New York.

Gibson, J. J. (1979) *The Ecological Approach to Visual Perception*. Houghton-Mifflin, Boston.

Hirsch, E. (1982) *The Concept of Identity*, Oxford Univ. Press, New York.

Kellman, P. J., and E. S. Spelke (1988) Perception of partly occluded objects in infancy. *Cog. Psychol.* **15**:483–528.

Landau, B., H. Gleitman, and E. S. Spelke (1981) Spatial knowledge and geometric representation in a child blind from birth. *Science* **213**:1275–1278.

Lockman, J. J., and D. H. Ashmead (1983) Asynchronies in the development of manual behavior. In *Advances in Infancy Research*, Vol. 2, L. P. Lipsitt and C. K. Rovee-Collier, eds., pp. 114–136, Ablex, Norwood, New Jersey.

Macomber, J., E. S. Spelke, and F. Keil (1988) Early development of the object concept: Knowledge of substance and gravity. *Infant Behav. Dev.* **11**:199.

Marr, D. (1982) *Vision*, Freeman, San Francisco.

Mill, J. S. (1965) An examination of Sir William Hamilton's philosophy. Excerpts reprinted in *A Source Book in the History of Psychology*, R. J. Herrnstein and E. G. Boring, eds., pp. 182–189, Harvard Univ. Press, Cambridge, Massachusetts.

Olson, G. M., and T. Sherman (1983) Attention, learning, and memory in infants. In *Handbook of Child Psychology* (formerly *Carmichael's Manual of Child Psychology*), Vol. 2, *Infancy and Developmental Psychobiology*, M. M. Haith and J. Campos, eds., pp. 1001–1080, Wiley, New York.

Piaget, J. (1954) *The Construction of Reality in the Child*, Basic Books, New York.

Quine, W. V. (1960) *Word and Object*, MIT Press, Cambridge, Massachusetts.

Schneider, B. A., and S. G. Trehub (1985) Infant auditory psychophysics: An overview. In *Measurement of Audition and Vision in the First Year of Postnatal Life*, G. Gottlieb and N. Krasnegor, eds., pp. 113–126, Ablex, Norwood, New Jersey.

Spelke, E. S. (1985) Preferential looking methods as tools for the study of cognition in infancy. In *Measurement of Audition and Vision in the First Year of Postnatal Life*, G. Gottlieb and N. Krasnegor, eds., pp. 323–363, Ablex, Norwood, New Jersey.

Spelke, E. S. (1988) Where perceiving ends and thinking begins: The apprehension of objects in infancy. In *Perceptual Development in Infancy*, A. Yonas, ed., Lawrence Erlbaum, Hillsdale, New Jersey.

Spelke, E. S., and R. Kestenbaum (1986) Les origines du concept d'objet. *Psychol. Fr.* **31**:67–72.

Streri, A. S. (1987) Tactile discrimination of shape and intermodal transfer in 2–3 month old infants. *Br. J. Dev. Psychol.* **5**:213–220.

Streri, A. S., and E. S. Spelke (1988) Haptic perception of objects in infancy. *Cog. Psychol.* **20**:1–23.

Wellman, H. (1985) The child's theory of mind: The development of conceptions of cognition. In *The Growth of Reflection*, S. R. Yussen, ed., Academic, New York.

Macomber, J., E. S. Spelke, and T. Keil (1988) Early development of the object concept: Knowledge of substance and gravity. *Infant Behav. Dev.* 11(191).

Marr, D. (1982) *Vision.* Freeman, San Francisco.

Mill, J. S. (1865) An examination of Sir William Hamilton's philosophy. Excerpts reprinted in *A Source Book in the History of Psychology*, R. J. Herrnstein and E. G. Boring, eds., pp. 168–169. Harvard Univ. Press, Cambridge, Massachusetts.

Olson, G. M., and T. Sherman (1983) Attention, learning, and memory in infants. In *Handbook of Child Psychology (formerly Carmichael's Manual of Child Psychology), Vol. 2, Infancy and Developmental Psychobiology*, M. M. Haith and J. Campos, eds., pp. 1001–1080. Wiley, New York.

Piaget, J. (1954) *The Construction of Reality in the Child.* Basic Books, New York.

Quine, W. V. (1960) *Word and Object.* MIT Press, Cambridge, Massachusetts.

Schneider, B. A., and J. G. Trehub (1985) Infant auditory psychophysics: An overview. In *Measurement of Audition and Vision in the First Year of Postnatal Life*, G. Gottlieb and N. Krasnegor, eds., pp. 113–126. Ablex, Norwood, New Jersey.

Spelke, E. S. (1985) Preferential looking methods as tools for the study of cognition in infancy. In *Measurement of Audition and Vision in the First Year of Postnatal Life*, G. Gottlieb and N. Krasnegor, eds., pp. 323–363. Ablex, Norwood, New Jersey.

Spelke, E. S. (1988) Where perceiving ends and thinking begins: The apprehension of objects in infancy. In *Perceptual Development in Infancy*, A. Yonas, ed., Lawrence Erlbaum, Hillsdale, New Jersey.

Spelke, E. S., and R. Kestenbaum (1986) Les origines du concept d'objet. *Psychol. Fr.* 31:67–72.

Streri, A. S. (1987) Tactile discrimination of shape and intermodal transfer in 2- to 3-month-old infants. *Br. J. Dev. Psychol.* 5:213–220.

Streri, A. S., and E. S. Spelke (1988) Haptic perception of objects in infancy. *Cog. Psychol.* 20:1–23.

Wellman, H. (1985) The child's theory of mind: The development of conceptions of cognition. In *The Growth of Reflection*, S. R. Yussen, ed. Academic, New York.