6 Where Perceiving Ends and Thinking Begins: The Apprehension of Objects in Infancy

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INTRODUCTION

Human adults experience the world as a layout of physical bodies that endure through time. Our ability to do this is both mysterious and fascinating, because the information we receive about physical objects is potentially so misleading. Consider the case of vision. Objects are bounded, but the visual scenes in which they appear are continuous arrays of surfaces. Somehow, we must determine which of the many surfaces that touch or overlap in a visual array are connected to one another. Objects are also integral units, but they are only partly visible at any given time and their visible surfaces are often separated from one another by nearer occluding objects. Somehow, we must recover the integrity of each object from this mosaic of visible fragments. Finally, objects exist and move continuously through space and time, but they are frequently occluded and disoccluded by movements of surfaces or of the observer. Somehow, we must apprehend the continuous existence of an object from our sporadic encounters with it. Vision, moreover, appears to provide the richest information for objects. The problems of apprehending objects only seem to increase when humans explore by listening or touching.

For centuries, philosophers and psychologists have attempted to understand how humans organize the world into objects by focusing on the origins of that ability. The most influential proposal has come from the empiricists. Perception, on this collection of views, begins with capacities to detect just the sensible properties of a scene, such as the surface fragments that reflect light to the eyes or resist the fingers' touch. Children construct a world of objects from this sensory tableau by learning about the consequences of their actions (e.g., Helmholtz, 1924; see also Piaget, 1954), and/or by learning how to use words to refer to parts of the world (e.g., Berkeley, 1910; Quine, 1960). One influential alternative to this view has come from the gestalt psychologists, who proposed that perceivers have an unlearned disposition to organize experience into maximally simple and regular units (Koffka, 1935; Kohler, 1929; Wertheimer, 1958). Even infants will perceive the unity, boundaries, and persistence of most objects, because objects tend to be relatively homogeneous in substance and regular in shape. Learning influences object perception, on the gestalt view, by modulating this organizing tendency.

These theories have been joined in recent years by several further approaches to perception. One is the ecological approach of James and Eleanor Gibson, which posits that perceivers apprehend properties of the world that are relevant to action by detecting invariant relationships in arrays of stimulation (E. J. Gibson, 1969, 1984; J. J. Gibson, 1966, 1979). Since the unity and boundaries of objects are highly relevant to early-developing human actions such as prehension and manipulation, mechanisms for detecting invariants that specify objects should become functional for humans at an early age. A different approach posits that perception depends on a hierarchy of computations performed by modality-specific and largely autonomous mechanisms. For example, a set of visual "modules" transforms the optic array into a succession of representations, each capturing deeper properties of the world (e.g., Marr, 1982). Although aspects of this view are akin to that of Helmholtz (1924), the empiricist background of Helmholtz's theory has been abandoned. Some or all of the mechanisms performing visual computations may be innate, on this view, and subsequent changes in their operation may depend primarily on maturation.

We have conducted research that suggests that all these approaches to object perception are wrong. In our studies of human infants, the organization of the perceptual world does not appear to mirror the sensory properties of scenes, it does not appear to follow from gestalt principles of organization, and it does not appear to depend either on invariant-detectors or modality-specific modules. Our research suggests that these views are wrong for a common reason. All assume that objects are *perceived*: that humans come to know about an object's unity, boundaries, and persistence in ways like those by which we come to know about its brightness, color, or distance. I suggest, in contrast, that objects are *conceived*: Humans come to know about an object's unity, boundaries, and persistence in ways like those by which we come to know about its material composition or its market value. That is, the ability to apprehend physical objects appears to be inextricably tied to the ability to reason about the world. Infants appear to understand physical events in terms of a set of principles that guide, as well, the organization of the perceived world into units.

The search for the mechanisms of object perception serves to organize the present chapter. In the first section, I consider whether objects are constructed from a sensory tableau, by asking if infants who cannot yet reach for objects or talk about them nevertheless organize the visual world into unitary bodies. A review of research with partly occluded objects suggests that they do, contrary to the empiricist thesis. Next, I consider whether object perception could arise from gestalt forces, by asking if infants group surfaces into objects in accord with gestalt principles of organization. Further research with partly hidden objects and with adjacent objects provides evidence against this thesis. In the third section, I consider whether objects are perceived through the detection of invariants in stimulation, by asking if infants perceive objects through a direct analysis of properties of the optic array. Studies of the interaction of different sources of information for object boundaries, as well as studies of the role of motion in specifying object unity, provide evidence that infants apprehend objects by analyzing properties of the perceived surface layout, not simply by detecting optical invariants. In the fourth section, I consider whether object perception depends on a modular visual process, by asking if separate mechanisms underlie infants' apprehension of objects in the visual and haptic modes. Research on haptic perception of objects provides preliminary evidence that a common, more central mechanism serves to organize the surface layout.

That last suggestion leads to a positive proposal: The apprehension of objects is a cognitive act, brought about by a mechanism that begins to operate at the point where perception ends. This mechanism begins not with the optic array but with the perceived surface layout, and it carves that layout into entities whose central properties are abstract. At a functional level, this mechanism can be considered a conception of the physical world. A review of research on infants' understanding of events involving fully hidden objects is presented as evidence for this proposal. That review also illustrates the fourfold conception of the physical world with which, I believe, infants are endowed: the initial object concept. In the final section, I attempt to sketch a general distinction between perception and thought, suggested by the foregoing analysis.

OBJECTS AS SENSORIMOTOR CONSTRUCTIONS

If objects are constructed from a sensory tableau, then the infant's initial experience of the world should mirror the world's sensible properties. A visual scene should be experienced as a mosaic of surfaces reflecting light to the eyes, and a tangible scene should be experienced as isolated patches of surfaces pressing against the body.

Different thinkers have had different ideas about the activities that trans-form this tableau into a world of objects. Some have proposed that objects are products of a culture, passed to the child by its older members. For example, it has been suggested that the construction of objects begins with the acquisition of language and especially the emergence of activities such as naming and expressing quantification and identity (e.g., Quine, 1960). Others have proposed that objects are constructed by the individual child, who acts on the world to uncover its regularities. In particular, the construction of objects has been rooted in the development of exploratory activities such as reaching and locomoting (Berkeley, 1910; Helmholtz, 1924) and in the developing ability to coordinate distinct exploratory actions into structures with certain formal properties (Piaget, 1954).

Our experiments provide a test of these views, for they were conducted with 3- to 5-month-old infants, and the earliest of the above activities (visually guided reaching) only begins to occur effectively during the 5th month. If any of these views were correct, then the infants in our experiments should experience each visual scene as a tableau of light-reflecting surfaces. None of our experiments accord with this prediction. In this section, I discuss the evidence that comes from one series of experiments, on 4-month-old infants' apprehension of partly occluded objects.

Philip Kellman, Hilary Schmidt, and I have studied infants' apprehension of an object whose ends are visible but whose center is hidden behind a second object (Fig. 6.1). Using a habituation procedure, we have presented infants with a single, center-occluded object on a succession of trials. Each trial lasted as long as the infant looked at the display, and it ended when he or she looked away for 2 seconds. The trials continued until the infant's looking time to this display declined by half, and then the infant was presented with new displays with no occluding object. One of these displays presented the unitary, continuous object that adults would have perceived. The other display corresponded to the visible areas of the original object and contained

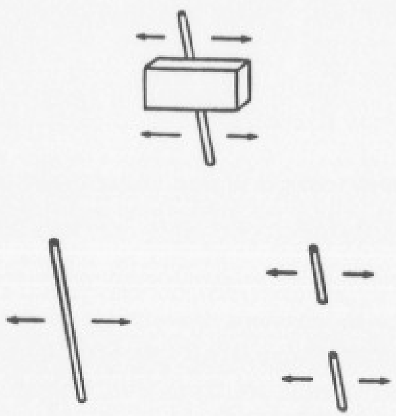

FIG. 6.1 Habituation display (top) and test displays from an experiment on perception of partly occluded objects (from Kellman & Spelke, 1983).

gaps at the occluder's former position. These displays were presented on 6 alternating trials, each trial lasting as long as the infant looked at the display.

In control experiments, we assessed baseline levels of looking at these displays, usually finding no preference. Against this baseline, we assessed post-habituation looking times to determine if habituation generalized more to one display than to the other. Experiments from a variety of laboratories indicate that habituation to a display containing several objects or forms will tend to generalize to a new display containing only some of those objects or forms, and that infants will tend to look longer at a new display containing new objects or forms (see Spelke, 1985a). This looking pattern is observed not only when infants are habituated to fully visible objects, but also when they are habituated to one object that partly occludes another (Kellman & Spelke, 1983; see Spelke, 1985a). If infants experience a partly occluded object as a tableau of visible surfaces, therefore, habituation should be followed by longer looking at the continuous object. If infants experience a partly hidden object as one connected unit, in contrast, habituation should be followed by longer looking at the separated visible fragments (see Kellman & Spelke, 1983, and Spelke, 1985a, for further discussion of this method and its underlying assumptions; see Schmidt & Spelke, 1984, and Termine, Hrynick, Kestenbaum, Gleitman, & Spelke, in press; for corroborative research using a different method).

We have now conducted experiments with a number of different displays of center-occluded objects (Kellman, Gleitman, & Spelke, in press; Kellman & Spelke, 1983; Kellman, Spelke, & Short, 1986; Schmidt & Spelke, 1984, 1985; Schmidt, Spelke, & LaMorte, 1986; Schwartz, 1982; Termine et al., 1986. Objects of a variety of forms, colors, and textures have been studied; some were two-dimensional and some were three-dimensional; some were presented in motion and some were stationary. No study, however, has provided evidence that infants experience a center-occluded object as a collection of visible surfaces.

More specifically, our experiments provide evidence that infants perceive a center-occluded object to continue behind its occluder if the visible ends of the object undergo a common motion. Habituation to a laterally translating center-occluded rod, for example, is followed by low levels of looking at a complete rod and higher looking at the fragmented ends of the rod separated by a gap (Kellman & Spelke, 1983; Fig. 6.2). Longer looking at the display with the gap cannot be attributed to the greater intrinsic attractiveness of that display, since there is no baseline preference between the test displays (Kellman & Spelke, 1983). Rather, habituation to the moving, center-occluded rod appears to generalize to the complete rod and to be followed by dishabituation to the broken rod. This pattern provides evidence that the infants perceive the continuity of the partly hidden object behind its occluder.

In our studies, 4-month-old infants have not been found to perceive the

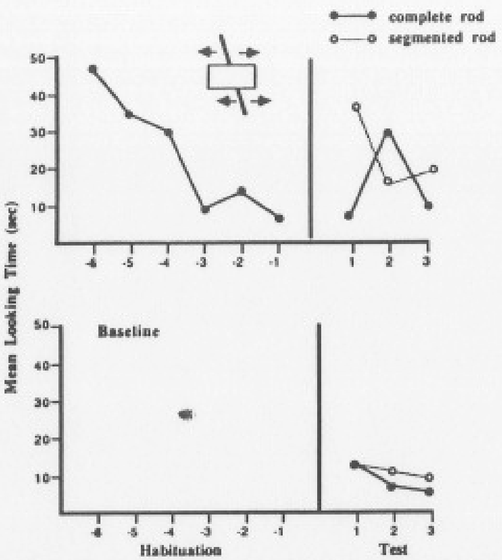

FIG. 6.2 Looking times to complete and broken rod displays after habituation to a center-occluded moving rod or an unrelated display (from Kellman & Spelke, 1983).

unity of a center-occluded object under all the conditions that are effective for adults. They fail to do this, for example, when the partly hidden object is stationary (see later). Even in this case, however, infants do not appear to perceive the object as a collection of visible fragments. Habituation to a stationary, center-occluded object is followed by marked and equal dishabituation to a complete and a broken object; it does not generalize to the latter display. These findings, as well as other findings to be presented in subsequent sections, provide evidence against the proposal that objects are constructed from a sensory tableau. Infants can perceive objects as continuous over occlusion before they can reach for objects, locomote toward surfaces, coordinate schemes into means-ends relationships, or use language.

Because the infants in our experiments were not newborns, one might propose that objects are constructed through activities taking place over the first 4 months. This proposal, however, would seem to lack much of the intuitive appeal of the original empiricist and Piagetian theses. Exploratory activity is limited in scope before 5 months of age, whereas there is an explosion of exploratory activity involving multiple perceptual systems after that time (see also Rochat, 1985; Hatwell, 1986). It was reasonable to propose, therefore, that infants construct a world of objects after the 5th month, much as scientists construct a world of particles, atoms, and molecules from their own converging investigations. About a year later, children begin to combine words and to develop a rapidly expanding repertoire of names for objects (see Gleitman & Wanner, 1982). It was reasonable to propose, therefore, that children carve their experiences into objects during the preschool years, as

they learn how words refer to the world and how nameable parts of the world are quantified and identified through time. There does not appear to be any comparable reason for situating the construction of objects before 5 months. Our findings therefore invite different accounts of the origins of knowledge of objects, to which we turn.

OBJECTS AS OPTIMAL FORMS

One alternative to the empiricist view has come from gestalt psychology (Koffka, 1935; Kohler, 1929; Wertheimer, 1958). Objects are perceived, on this view, by virtue of an inherent tendency of the nervous system toward a state of equilibrium. This physical tendency has a psychological counterpart: Perceivers tend to organize the visual world into units of maximal simplicity and regularity on every dimension that their perceptual systems can register. Because human adults are sensitive to color and pattern, shape, and substance, adults tend to group surfaces into units that are maximally regular on those dimensions.

Our experiments serve to test the gestalt thesis, because infants of the ages we have studied have been found to be sensitive to color (e.g., Peeples & Teller, 1975), texture (e.g., Fantz, Fagan, & Miranda, 1975), substance (e.g., E. J. Gibson & Walker, 1984) and form (e.g., Schwartz & Day, 1979). Young infants have been shown to detect gestalt relationships such as good continuation (van Giffen & Haith, 1984) and symmetry (Bornstein, Ferdinandsen, & Gross, 1981; see Banks & Salapatek, 1983; and E. J.Gibson & Spelke, 1983, for reviews of this evidence). We may ask, therefore, whether infants organize visual scenes into objects by analyzing the gestalt properties of scenes. The evidence suggests consistently that they do not.

The first evidence comes from studies of infants' apprehension of partly occluded objects. When a stationary, center-occluded object is homogeneous in color and texture, smooth in contours, and simple in shape, the gestalt principles of similarity, good continuation, and good form dictate that the object continues behind its occluder. Adults report that such objects look continuous over occlusion (Kellman & Spelke, 1983; Schmidt, 1985). Our experiments provide no evidence, however, that 4-month-old infants experience such objects as continuous. Whether infants are presented with a rod, a triangle, a rectangular or oval flat surface, or a solid, uniformly colored cube or sphere, habituation to a center-occluded object is followed by equal dishabituation to a complete object and to two visible fragments separated by a gap (Kellman & Spelke, 1983; Schmidt & Spelke, 1984; Schmidt et al., 1986; Schwartz, 1982; Termine et al., 1986; see Fig. 6.3). We believe that an infant's experience of these objects is indeterminate, as is an adult's experience of a partly occluded object with an *ir*regular form. The visible surfaces

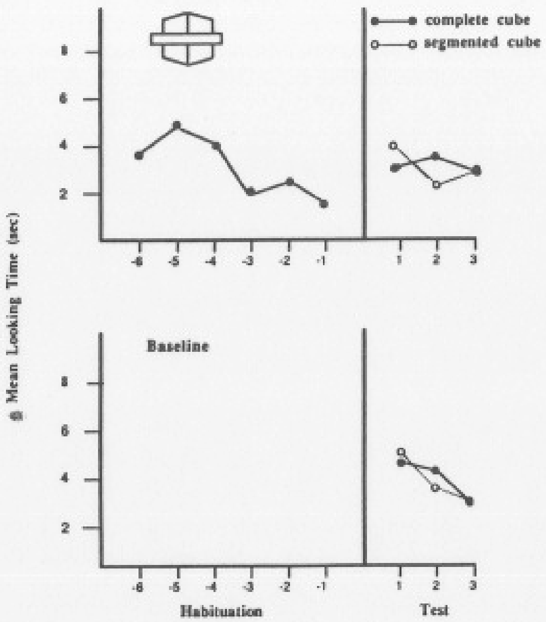

FIG. 6.3 The principal findings of one experiment on perception of stationary, partly occluded forms. After habituation to a center-occluded cube of a uniform color and texture, or after exposure to an unrelated display, infants were tested with complete and broken cube figures. Test trial looking preferences were not affected by the prior period of habituation (from Schmidt & Spelke, 1984).

of the object are neither seen as definitely connected nor seen as definitely separated behind the occluder.

Why do young infants apprehend the unity of a regularly shaped, center-occluded object if it moves but not if it is stationary? One possibility is that motion draws attention to a partly hidden object, allowing infants to perceive its complete shape by analyzing its gestalt properties. Our experiments provide two lines of evidence against this possibility. First, many patterns of motion increase infants' attention to a center-occluded object, but only certain motion patterns lead infants to perceive the object as complete. When infants are presented with a rod and block that move together, for example, they watch the display attentively, but they do not generalize habituation to a complete rod (Kellman & Spelke, 1983; see also Kellman & Short, 1985). Second, motion leads infants to perceive the unity of an object, irrespective of the object's gestalt properties. After habituation to two commonly moving surfaces that are dissimilar and misaligned, infants dishabituate to a broken display and generalize habituation to a complete object just as strongly as they do after habituation to commonly moving surfaces that are similar and

aligned and that form a simple shape (Kellman & Spelke, 1983, Fig. 6.4). For adults, the apparent unity of a moving, center-occluded object is influenced by the object's regularity of shape, texture, and coloring, in accord with the gestalt analysis (Kellman & Spelke, 1983). For infants, in contrast, apprehension of the unity of an object depends only on the object's motion. This finding provides evidence against the view that infants perceive object unity by virtue of gestalt forces.

Because these studies focused only on perception of party occluded objects, it remained possible that gestalt properties would influence other aspects of object perception. In particular, relationships of good continuation and similarity provide adults with information about object boundaries: When two objects touch, adults tend to perceive them as separate units if the objects differ in color and texture and if their surfaces and edges are misaligned. Our next experiments investigated whether infants apprehend object boundaries by detecting these gestalt relationships.

Infants' apprehension of object boundaries was investigated by means of four experimental methods: a habituation of looking time method (Kestenbaum, Termine, & Spelke, in press), a method for assessing object-directed reaching (Hofsten & Spelke, 1985; Spelke, Hofsten, & Kestenbaum, 1986), a method for assessing immediate reactions of surprise or curiosity to objects that move together versus separately (Spelke & Born, 1983; Spelke, Born, Mangelsdorf, Richter, & Termine, 1983; see Spelke, 1985b), and a number detection method (Prather & Spelke, 1982). The reaching experiments were conducted with 5-month-old infants; the other experiments were

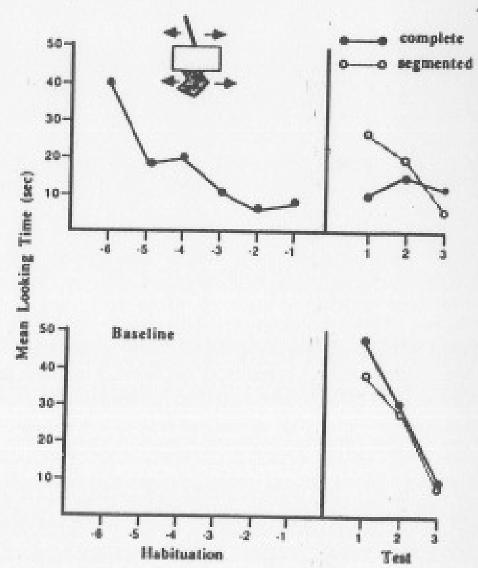

FIG. 6.4 Looking times to complete and broken displays after habituation to a center-occluded irregular figure, or after no habituation sequence (from Kellman & Spelke, 1983).

conducted with 3-month-old infants. Because the findings of all the experiments support the same conclusions, only the studies using the reaching method are described.

Infants were presented with two blocklike objects of the same color and texture that were arranged in depth, the smaller object in front of the larger one (Fig. 6.5). The objects either touched in depth or were separated by a small gap; their adjacency or separation was achieved by varying the thickness of the closer object, leaving constant all other properties of the objects. Infants viewed these displays binocularly from a seat that permitted considerable head movement; the depth relationships in the displays were specified by all the major depth cues including binocular disparity, optical flow, and kinetic occlusion. Because the two objects in a display differed in size and shape and were presented such that no surfaces or edges of one object were aligned with those of the other, gestalt factors dictated that the two objects in each display were distinct.

To investigate how infants organized these displays, an infant was seated within reaching distance of both objects and his or her object-directed reaching was observed. A *reach* was defined as any contact of the palmar surfaces of the infant's fingers with an object, provided that the hand decelerated as it approached the object and the fingers came to rest upon it; "swiping" was not considered. A new reach was scored every time the hand was lifted and came to rest upon the object again. Each reach was scored as a reach for the closer object, the more distant object, or both objects, depending on where the hand(s) contacted the display.

How can infants' patterns of reaching in this situation provide information about their perception of object boundaries? Our own experiments and those from other laboratories indicate that infants who are presented with a single object tend to reach for it by grasping its lateral borders (Bower, Dunkeld, & Wishart, 1979; Hofsten, personal communication; Spelke & Hofsten, 1986). If infants perceived the two objects as a single unit, therefore, they were expected to reach either for the edges of the larger, more distant object (which provided all the lateral borders of the display) or for both objects simultaneously.

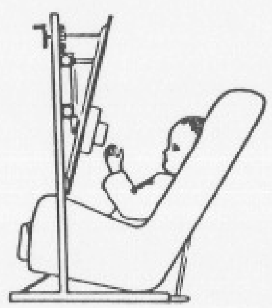

FIG. 6.5 Side view of the adjacent-objects display in an experiment assessing object-directed reaching (from Hofsten & Spelke, 1985).

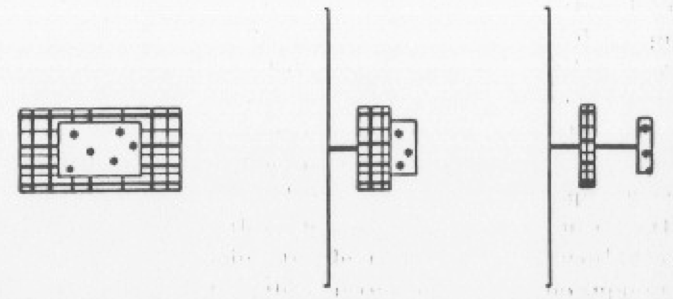

FIG. 6.6 Front view (left) and side views of the displays used in an experiment on perception of object boundaries (from Kestenbaum, Termine, & Spelke, in press).

Other experiments indicate that infants who are presented with two visibly separated objects tend to reach for the object that is closer (Yonas & Granrud, 1984). If infants perceived the two objects as separate, bounded units, therefore, they were expected to reach primarily for the smaller, closer object without contacting the larger object (see Hofsten & Spelke, 1985, and Spelke & Hofsten, 1986, for more discussion of these predictions).

When the two objects were separated in depth, the infants tended to contact the nearer and smaller object, suggesting that they organized the display into two separate units. When the objects were adjacent, the infants tended to contact the larger and more distant object, suggesting that they organized the display into a single unit (Hofsten & Spelke, 1985). Although relations of good continuation and good form dictated that the objects in both displays were distinct, infants treated the objects as separate only if they were separated in depth.

This last finding has been corroborated and extended by experiments with other displays. For example, 3-month-old infants were presented with two stationary objects that differed in color, texture, and substance and that were arranged in depth such that they either touched or were separated by a gap (Kestenbaum et al., in press; Fig. 6.6; see also Piaget, 1954; Prather & Spelke, 1982; Spelke et al., 1983). Adults reported that each of these displays consisted of two distinct objects, in accord with gestalt principles of good continuation, good form, and similarity (Kestenbaum et al., in press). In contrast, the experiments provided evidence that the infants' organization of the displays depended only on the objects' spatial arrangement: The two objects were perceived as separate units when they were spatially separated and as one unit when they were adjacent (Fig. 6.7).

These experiments provide evidence that young infants apprehend object boundaries by detecting the three-dimensional arrangements of surfaces—a finding that further undermines the thesis that the visual world begins as a sensory tableau. Nevertheless, the experiments provide no support for the

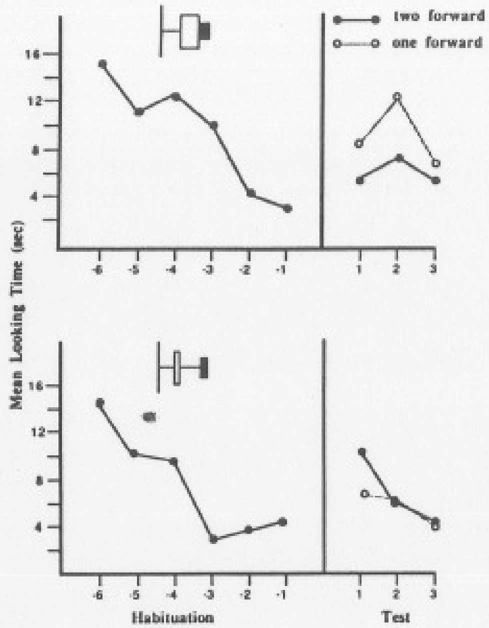

FIG. 6.7 Looking times to a display of two objects after a displacement that preserved (filled circles) or changed (open circles) the objects' arrangement. After habituation to adjacent objects, infants looked longer at a display that changed the objects' arrangement, suggesting that the objects were originally seen as a single unit. This pattern was not obtained after habituation to objects that were separated in depth (from Kestenbaum et al., in press).

traditional alternative to this thesis, that the visual world of infants is organized in accord with gestalt principles of organization. Young infants do not appear to perceive either the unity or the boundaries of objects by virtue of a general tendency to confer the simplest, most regular organization on a scene.

Recent studies by Hilary Schmidt suggest that children begin to organize visual scenes in accord with the gestalt principles of similarity and good continuation at some time between 5 months and 2 years of age. Two-year-old children, like adults (Schmidt, 1985), are able to apprehend the unity and boundaries of a stationary, partly occluded form by detecting whether its visible surfaces match in color and texture and whether its visible edges are aligned (Schmidt & Spelke, 1985). Five-month-old infants have neither ability (Schmidt et al., 1986). Although the causes of this developmental change are not clear, Schmidt suggests that children may learn that good continuation and color similarity are useful cues to object boundaries, as Brunswik (1956) earlier proposed.

It might be pointed out that the present experiments support two predictions from gestalt theory, because infants were found to organize visual displays in accord with the principle of "common fate" and a principle of (three-dimensional) "proximity." These findings do not imply, however, that the gestalt analysis of object perception is partly correct. According to gestalt theory, all the principles of organization are surface manifestations of a

single tendency to maximize the simplicity of the perceived world. Our research suggests, in contrast, that young infants only seek simplicity of certain kinds. Although infants can detect configurations of shape and color in the surface layout, they do not organize the layout into units that maximize the regularity of those configurations. Infants apprehend objects by analyzing surface arrangements and movements, but not because of any general tendency to confer the most regular organization on the world. We turn now to other attempts to account for this capacity.

OBJECTS AS SPECIFIED BY OPTICAL INVARIANTS

According to J. J. Gibson, humans and other animals perceive the persisting and changing structure of the world around them by detecting unchanging, higher-order relationships in stimulation: optical, acoustic, or haptic *invariants*. The research described so far would seem to support a Gibsonian approach to object perception, because infants appear to apprehend objects by detecting the spatial and kinetic relationships among surfaces, and these relationships are just the sorts of properties that optical invariants specify (see J. J. Gibson, 1979). Further studies, however, have provided two sorts of evidence against the thesis that an invariant-detection mechanism underlies infants' perception of objects. First, experiments suggest that spatial and kinetic information for object boundaries interact in ways not predicted by the invariant-detection thesis. Second, experiments suggest that the mechanism for apprehending objects takes as input the spatial layout as it is perceived; it does not respond directly to invariants in the optic array.

If infants perceive objects by detecting invariants specifying the arrangements and motions of surfaces, then the perceived unity and boundaries of objects should be a relatively simple function of the invariant information available. Distinct invariants might have additive effects on perception, for example, or some invariants might dominate others. When infants apprehend object boundaries, however, spatial and kinetic relationships interact in a way that is not easily assimilated to an invariant-detection framework.

The interaction of spatial and kinetic information for object boundaries has been investigated through studies of object-directed reaching (Hofsten & Spelke, 1985; Spelke et al., 1986). In experiments using the method described in the last section, infants were allowed to reach for pairs of objects that were stationary, that moved together, or that moved independently. The objects were either adjacent or separated, and they were arranged either vertically or in depth. When the objects moved, they underwent a lateral translation, as in Kellman and Spelke's (1983) experiments. Either the objects moved together in a manner that preserved their rigid arrangement, or one object moved relative to the other.

Our first studies investigated whether movement affects infants' perception of the boundaries of objects arranged in depth. Infants were allowed to reach for two objects that were adjacent or separated in depth and that underwent common or relative motion. Whether the objects were adjacent or separated, the infants reached for the objects as a single unit when they moved together, and they reached for the closer object as a separate unit when either object moved relative to the other (Hofsten & Spelke, 1985). Infants thus appear to organize rigidly moving surfaces into a single object when the surfaces are arranged in depth, just as they do when surfaces are partly hidden by a common occluder (Kellman & Spelke, 1983), and they appear to organize independently moving surfaces into separate units. Kinetic information therefore takes precedence over spatial information in specifying the boundaries of objects that are arranged in depth.

The next studies investigated the interaction of spatial and kinetic information when objects are arranged vertically, such that their adjacency or separation is directly visible (Spelke et al., 1986). Infants were presented with vertically adjacent or separated objects: a small, thick object above a larger, thinner object. The objects were arranged so that the smaller object was closer to the infant and the larger object provided most of the lateral borders of the display (Fig. 6.8). When these objects were stationary, infants reached for the adjacent objects as a single unit and for the closer of the separated objects as a distinct unit, just as when stationary objects are arranged in depth (Hofsten & Spelke, 1985). In the principal experiments, therefore, infants were allowed to reach for either the vertically adjacent objects or the vertically separated objects as the objects moved together or independently. Reaching for the adjacent objects depended once again on the pattern of motion: Infants reached for the two objects as a single unit when they moved together, and they reached for the closer of those objects as a separate unit when they moved independently. With the visibly separated objects, in contrast, reaching was not influenced by the motion patterns. Infants reached for the closer object as a separate unit both when the objects moved independently and when they moved together. Two commonly moving objects do not appear to be organized into a single unit if they are separated by a visible gap.

These experiments suggest that infants organize the layout into entities that are *cohesive* and *bounded*: spatially connected bodies that are distinct from one another and that retain their connectedness and their boundaries as they move. This finding ill accords with the thesis that objects are perceived by mechanisms for detecting invariants, because the object properties of cohesion and boundedness, unlike the surface properties of spatial contiguity and common movement, do not appear to be specified by optical invariants. Whether we as adults take a set of surfaces to lie on one cohesive body depends, in part, on what we infer about unseen parts of the layout. When surfaces are separated in depth, a pattern of common motion leads us to infer

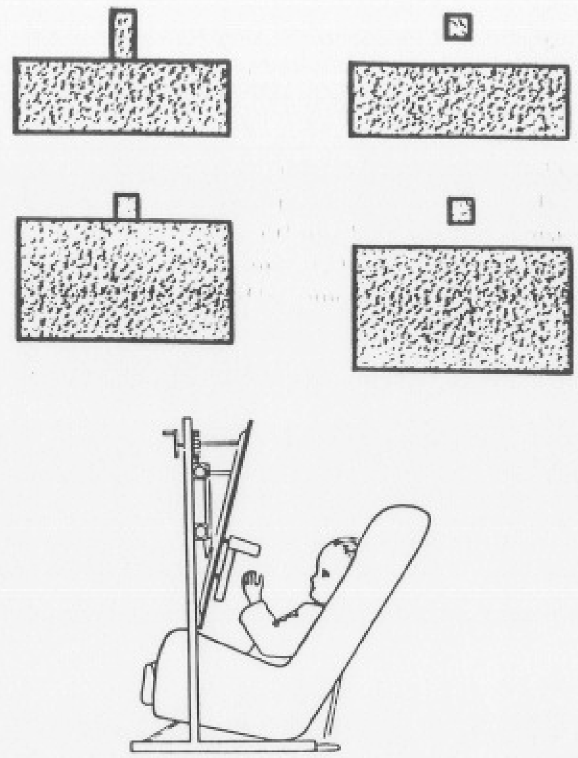

FIG. 6.8 Front views of the vertically adjacent and separated objects, and side view of the adjacent objects and the apparatus for an experiment assessing object-directed reaching (from Spelke et al., 1986).

that the surfaces are connected, because we assume that surfaces on distinct bodies will not act on each other at a distance and move together. When two visibly separated surfaces move together, in contrast, no inference of a direct connection between them is possible. The surfaces are organized differently, even though their visually specified motions are the same as in the first case.

Further evidence against the invariant-detection thesis was provided by studies that probed the nature of the kinetic relationships that lead infants to apprehend the unity of a center-occluded object. Credit for these studies goes to Philip Kellman and to his laboratory at Swarthmore College (although he is not responsible for the use I make of them). Kellman asked whether the apprehension of object unity depends on an analysis of proximal motion—the displacements of elements in the optic array—or an analysis of distal motion—the translation of an object through the three-dimensional layout. This question is quite difficult to answer, because every perceivable distal motion in the layout is accompanied by some proximal change. The effects of proximal and distal motion can be distinguished, nevertheless, by focusing on situations in which similar distal motions give rise to different patterns of proximal change, or the reverse. Kellman's research focuses on several of these situations.

First, Kellman asked whether vertical translation and translation in depth have the same effect as horizontal, lateral translation on infants' perception of object unity (Kellman, Spelke, & Short, 1986). Vertical and depth translations were studied, because these motions are specified by different optical invariants, and in each case the invariants differ from those that specify lateral translation. When the object in these studies (a center-occluded rod) was translated vertically, the only proximal change concerned the length of the images of its visible surfaces: the bottom shortened as the top lengthened, and vice versa. When the object was translated in depth, the images of its visible surfaces shrank and expanded in unison. When the same object was translated laterally, the images of its surfaces did not change in any dimension: Instead, they underwent a common horizontal displacement if the infant's point of fixation remained fixed, and they remained together in a relatively constant retinal position if the infant tracked the object. The experiments provided evidence that infants apprehended the unity of the object under all three motion conditions (Fig. 6.9). Lateral translation, vertical translation, and translation in depth all appear to specify to infants than an object continues behind its occluder.

This finding suggests that infants apprehend object unity by detecting distal rather than proximal displacements. The study is not conclusive, however, because each of the three distal displacements involves some unitary proximal change. Perhaps the experience of objects depends on a collection of invariant detectors, each attuned to a different kind of optical change. We attempted to test that possibility by presenting infants with object displays in which there was no distal change, or no proximal change, in the visible ends of an object.

In these experiments (Kellman, Gleitman, & Spelke, in press), infants were placed in a movable seat on a semicircular track, and they observed a center-occluded object while they themselves were in motion (Fig. 6.10). In the "proximal motion" condition, the object was stationary, and movements of the infant caused displacements of the images of its visible surfaces. In the "distal motion" condition, the object moved synchronously with the infant so as to cancel this lateral displacement: The images of its visible surfaces thus remained centered in the field of view. The extent and speed of the infant's motion were such that the first condition presented about the same amount of proximal displacement, and the second condition presented about the same amount of distal displacement, as in our earlier experiments with stationary infants and moving objects. Patterns of dishabituation in the proximal motion condition closely resembled the patterns shown in earlier

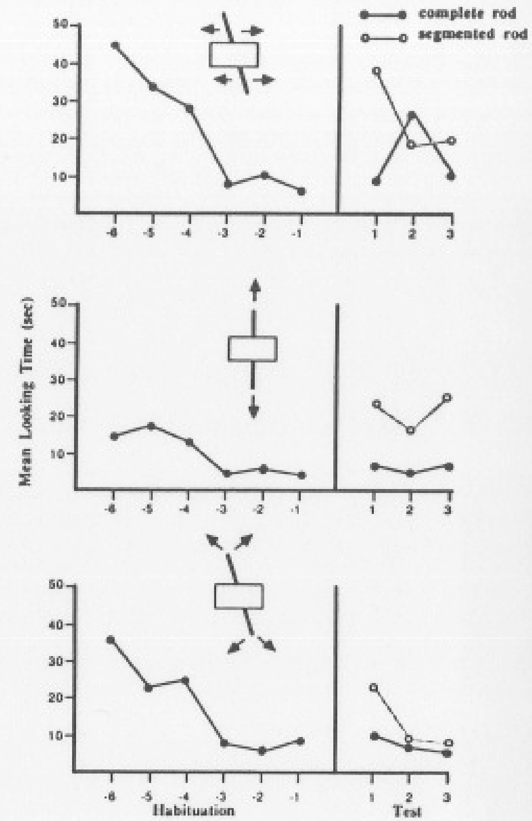

FIG. 6.9 Looking times to complete and broken rod displays after habituation to a rod that moved laterally, vertically, or in depth. Infants in baseline groups (not shown) exhibited no preferences between these displays (from Kellman & Spelke, 1983, and Kellman et al., 1986).

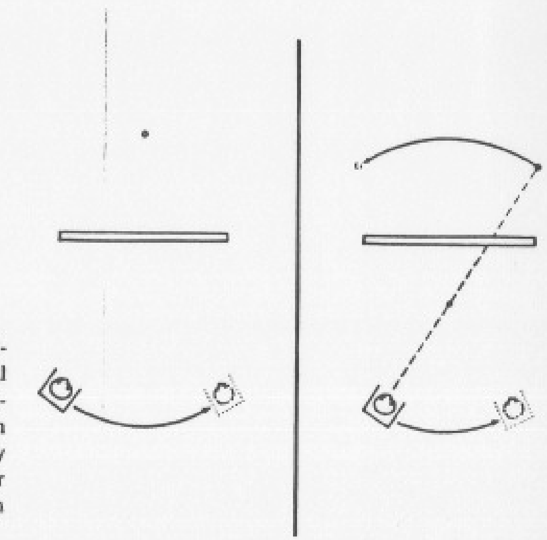

FIG. 6.10 Top view of the experimental situation in the proximal motion condition (left) and the distal motion condition (right) of an experiment on perception of partly occluded objects during observer motion (from Kellman et al., in press).

experiments with a stationary baby and stationary objects: Infants dishabituated equally to the complete and broken objects. In contrast, patterns of dishabituation in the distal motion condition closely resembled the patterns shown in earlier experiments with a stationary baby and moving objects: Infants generalized habituation to the complete object and looked longer at the broken object (Kellman et al., in press, Fig. 6.11). Infants' apprehension of object unity thus appears to depend only on the three-dimensional motions of visible surfaces, not on the displacement of the images of those surfaces at the eyes.

These experiments provide evidence that the organization of visual scenes into objects depends on an analysis of changes in the perceived, three-dimensional surface layout. Apprehending objects appears to be at least a two-step process, in which infants first perceive the three-dimensional arrangements and motions of surfaces in the layout, and then they analyze those surface arrangements and motions so as to form units that are cohesive and bounded. It remains possible that infants perceive surface arrangements and motions by detecting optical invariants (see E. J. Gibson, 1984, and Banks, this volume), but optical invariant detectors do not appear to organize the layout into objects. Objects are apprehended only after the lay-

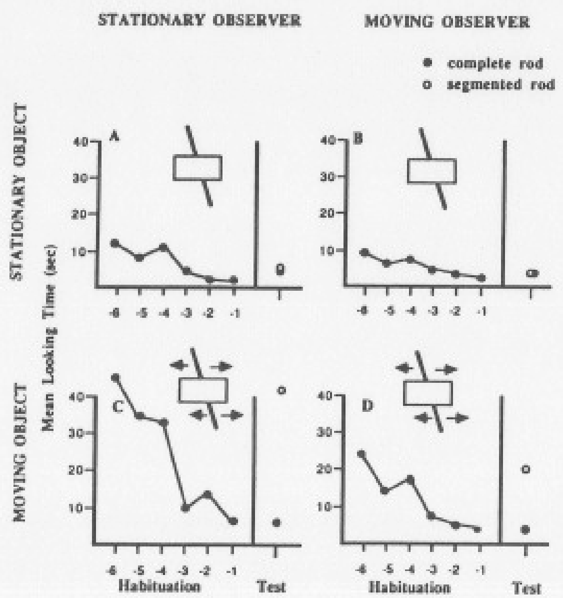

FIG. 6.11 Looking times on the first test trial to complete and broken rod displays after habituation, during observer motion, to a center-occluded rod with (b) proximal or (d) distal motion. Results of the comparable experiments with no observer motion appear in (a) and (c) (from Kellman et al., in press, and Kellman & Spelke, 1983).

out is perceived, by virtue of a process that would seem to be inferential in character.

These findings are compatible with the thesis that object perception depends on a system of visual modules performing a hierarchy of computations on progressively more abstract, behaviorally appropriate representations of the optic array. Alternatively, object perception may not depend on a visual mechanism at all but on a mechanism that is more central. The research described in the next section begins to distinguish these possibilities.

OBJECT PERCEPTION AS A MODULAR VISUAL PROCESS

The experiments to be described focus on one likely difference between mechanisms of perception and mechanisms of thought. Each perceptual system operates on one kind of physical stimulation, computing representations of the layout in accord with constraints on the way the layout is projected in that sensory mode (see Marr, 1982). Mechanisms of visual and auditory localization function differently, for example, even though they converge ultimately on a unitary representation of spatial position. If modality-specific modules organize the world into objects, therefore, objects might be perceived in different ways when they were seen, heard, and felt. Mechanisms of thought, in contrast, do not center on a single modality but operate on the world as it is perceived, regardless of the sensory source of one's perception. If a single, relatively central system organizes the world into objects, objects should be apprehended under the same conditions, barring sensory limitations, whether surfaces were encountered by looking, listening, or touching.

Research on infants can serve to investigate these alternatives.[1] Four-month-old infants have been found to apprehend objects visually by detecting some, but not all, of the relationships that specify objects to adults: They respond to the movements and arrangements of surfaces but not to gestalt relationships such as good continuation. If object perception depends on one central mechanism, then the same findings should be obtained when young infants encounter surfaces by touch. Use of gestalt relationships should emerge at the same age, moreover, when children feel objects as when they see them. Arlette Streri and I have begun experiments to test these predictions (Steri & Spelke, in press).

The ability to apprehend objects by touch is of interest in itself. At any given time, a perceiver's hands are in contact with only small parts of sur-

[1] I am grateful to Barbara Landau and Ulric Neisser for pointing this out to me and for suggesting the present line of reseach.

faces, and he or she discovers properties of those surfaces by actively moving the hands across them (J. J. Gibson, 1962). How do perceivers apprehend a stable and continuous surface layout from these partial, changing encounters, and how do they organize that layout into objects?

The problem of perceiving objects by touch is perhaps clearest when humans explore with two hands a layout they cannot see. Consider the case in which an adult grasps two surfaces, one in each hand, and seeks to determine whether or not the surfaces lie on a single object. Short of feeling the space between the surfaces, the adult will probably attempt to recognize the object(s) on which the surfaces lie, to analyze gestalt relations between the surfaces, and/or to displace the surfaces and observe whether they move together. Streri and I focused on just this situation, asking how young infants organize such displays. In particular, we asked whether infants would perceive two surfaces that could only be moved rigidly together as parts of one connected object, and if they would perceive two surfaces that could be moved independently as parts of two separate objects.

Our experiments were based on a haptic habituation method developed by Streri and Pêcheux (1986a, 1986b). Infants aged 4 to 5 months were allowed to hold two ring-shaped objects, one in each hand, under the cloth that blocked their view of the objects and their own bodies (Fig. 6.12). In one condition, these objects were rigidly connected by a narrow bar; in the other condition, they were connected by an elastic band that allowed them to move independently. Infants were free to explore the objects at will during a series of trials. Each trial began when one pair of rings was placed in the infant's hands and ended when the infant dropped a ring; the trial sequence continued until holding time had declined, on three successive trials, to half its original level. Infants were found to displace the rings actively, producing patterns of rigid motion in one case and patterns of independent motion in the other case. Curiously, few infants tried to feel the central area between the rings or to bring the rings into view (those who did could be eliminated from subsequent analyses without changing the findings). Rather, infants tended to clutch each ring with few movements of the fingers, and they tended to move their hands and arms, displacing the rings together or independently.

To investigate whether these motion patterns were discriminable, the first experiment followed this period of familiarization with a haptic test in which the infants were presented with the rigidly and independently movable rings on alternating trials. The results revealed both a tendency to explore the independently movable rings longer than the rigidly movable rings, and a tendency to explore the novel rings longer than the familiar rings (Fig. 6.13). Both effects provided evidence for the discriminability of the motion patterns.

The second experiment investigated whether this discrimination would transfer to vision. After the period of haptic familiarization, infants were given a visual test: The rings were removed from the infant's hands, the

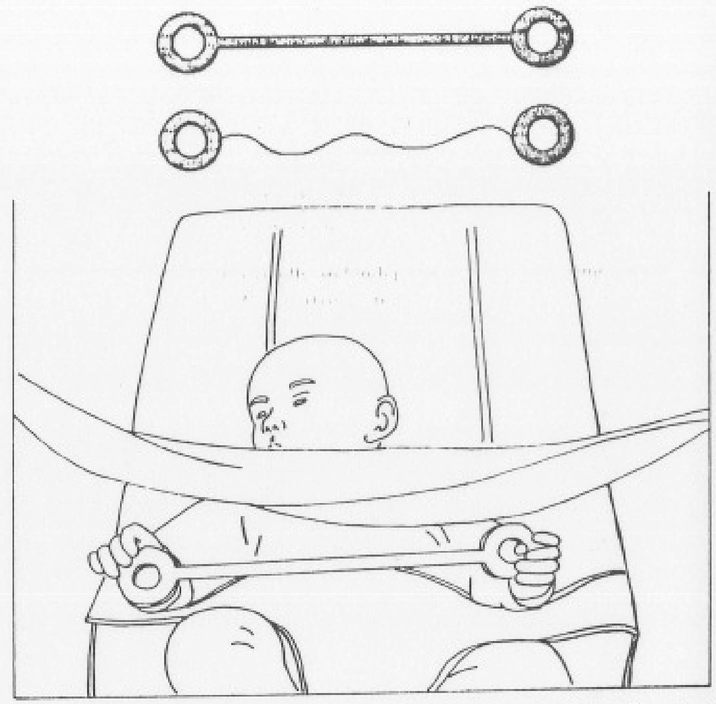

FIG. 6.12 Objects and apparatus for experiments on haptic exploration of objects (from Streri & Spelke, in press).

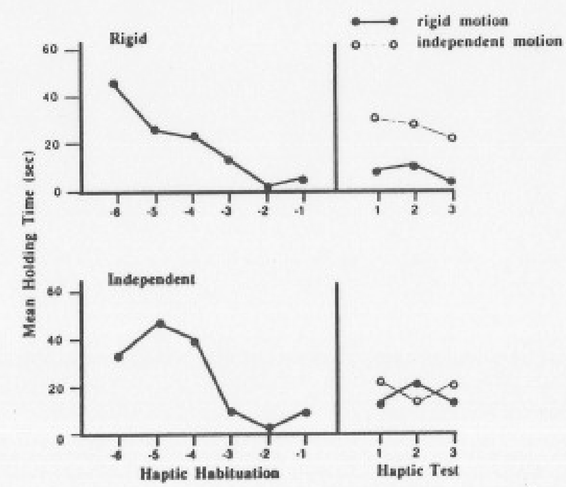

FIG. 6.13 Holding times for rigidly and independently movable rings after haptic habituation to one or the other display (from Streri & Spelke, in press).

occluding cloth was dropped, and the two pairs of rings were presented visually on alternating trials, undergoing their characteristic motions. Infants tended to look longer at the rings that underwent a novel motion: Habituation tended to generalize, and discrimination to transfer, from the haptic to the visual modality (Fig. 6.14). This transfer does not indicate in itself that the mechanisms of object perception are amodal, however, since transfer could be mediated by independent visual and haptic mechanisms that give matching outputs. To investigate whether a single mechanism underlies the apprehension of objects by vision and by touch, one must study the conditions under which objects are apprehended in each mode.

Accordingly, a third experiment investigated whether the haptically produced patterns of common or independent motion specified the connectedness or separateness of the rings. In this experiment, the haptic familiarization period was followed by a visual test in which two different ring displays underwent the same jiggling motion. Only the connectedness or separateness of the rings differentiated the two test displays: In one display, the rings were visibly connected by a bar and thus lay on one object; in the other display, the rings were visibly separated. Both experiments yielded the same finding: Infants who were habituated to the rigidly movable rings tended to look longer at the visibly separated rings, whereas those who were habituated to the independently movable rings tended to look longer at the visibly connected rings (Fig. 6.15). Infants who displaced surfaces in a common rigid motion evidently organized the surfaces into a single connected object; infants who displaced surfaces independently evidently organized the surfaces into two distinct objects.

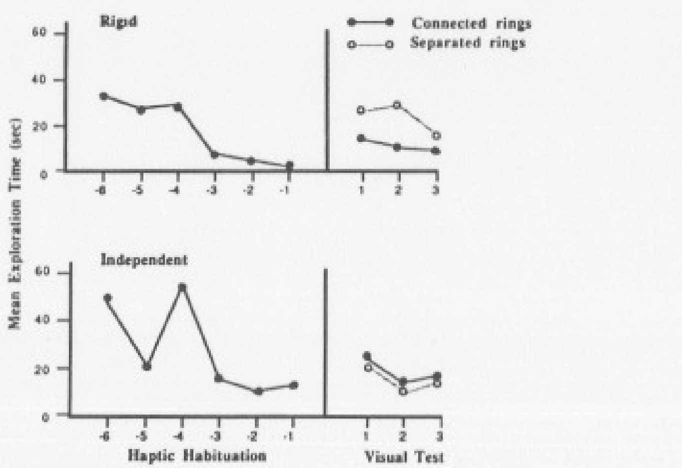

FIG. 6.14 Looking times to connected and separated rings undergoing their characteristic motions, after haptic habituation to rigidly movable or independently movable rings (from Streri & Spelke, in press).

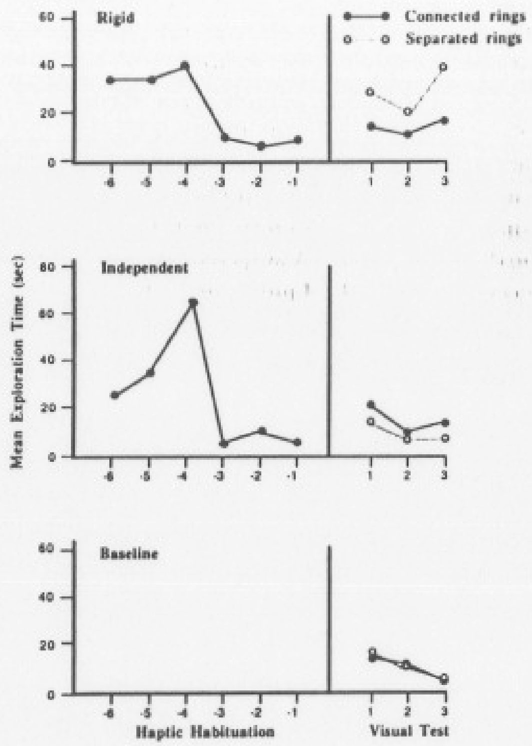

FIG. 6.15 Looking times to connected and separated rings undergoing no distinctive motion, after haptic habituation to rigidly or independently moveable rings or after no habituation period (from Streri & Spelke, in press).

These findings provide evidence that infants apprehend the unity and boundaries of objects in the haptic modality as they do in the visual modality, by detecting the common and independent motions of surfaces. Such evidence supports the hypothesis that a common, relatively central mechanism organizes the surfaces that infants see or feel into objects. We have now tested that hypothesis further by investigating when children begin to apprehend objects haptically by detecting gestalt relationships such as sameness of texture and substance and alignment of surfaces and edges. Our evidence suggests that this tendency is absent at 4 months, as in the case of vision.

Even if the evidence continues to suggest that objects are apprehended by an amodal mechanism, one might question how central that mechanism is. Fodor (1983) has suggested that certain modular systems are not modality specific and yet are genuinely *perceptual* systems distinct from thought; the language system is offered as an example. I doubt, however, that mechanisms for apprehending objects can be distinguished from mechanisms of thought in any sense, for our research suggests that the processes by which infants find objects in the world are tied to the processes by which they understand physical events. This point is best made by the research described in the next section, which focuses on infants' understanding of events in which objects become fully hidden.

OBJECTS AS PRODUCTS OF THOUGHT

Central mechanisms for understanding the world do more than give sense and order to perceived events: They carry perceivers beyond their immediate surroundings and allow them to apprehend properties of the world that cannot be sensed. Thus, as Piaget (1954) and others have proposed, a true object concept enables one to keep track of the existence, the behavior, and the location of objects that are fully hidden and to predict, to some degree, the future course of events involving those objects. The next experiments investigated whether infants have such abilities.

When an object moves fully out of view for more than several seconds, most adults would no longer say that it is "perceived": Awareness of objects does not long keep the character of an immediate experience (Michotte, Thinès, & Crabbé, 1964). Under many conditions, nevertheless, a witness to an object's disappearance knows if the object still exists, where it is, and what it is doing. Notions of various kinds contribute to her understanding of events in which objects move from view. Consider, for example, the case of a pencil that is dropped behind a screen that stands on a table. An adult who observed this event would predict that the pencil will come to rest upon the table, and not above or below it, in accord with the notion that *objects are subject to gravity* and cannot stand unsupported in midair, and the notion that *objects are substantial* and cannot pass freely through other objects. She would also predict that the pencil will reach its resting place on the table by following a connected path. This prediction follows from the notion that *objects are spatiotemporally continuous*: They cannot pass from one place to another without moving on a continuous path between them. Further predictions might concern the pencil's direction and speed of motion, in accord with notions concerning physical forces (some of which are erroneous: e.g., Clement, 1982; McCloskey, Caramazza, & Green, 1980). Finally, an adult would predict that the hidden pencil will remain a yellow, elongated object that affords writing; this prediction follows from notions concerning the constancy of object substances, forms, and functions over free movements through the layout.

What are the origins of capacities to make sense of events involving hidden objects? An enormous collection of studies has addressed this question using

search tasks developed by Piaget (1954). These studies reveal that the ability to search for and recover occluded objects develops over the first 18 months in a regular sequence of stages. A predictable developmental sequence can be discerned not only when infants search manually but also when they search visually, although the development of visual search is more rapid (Harris, 1983). Studies of object-directed search do not reveal, however, whether these developments stem from changes in infants' conceptions of hidden objects or changes in infants' capacities to act. Curiously, research by Piaget (1952) provides strong presumptive support for the latter possibility. For example, Piaget found that young infants cannot coordinate separate acts into means-ends relationships, as systematic search requires. The inability to coordinate means with ends would limit young infants' search for hidden objects, even if the infants conceived of such objects as existing continuously. It appears necessary, therefore, to investigate infants' knowledge of the continued existence of occluded objects by means of methods requiring no coordinated search. Our research, and a growing body of research by Renée Baillargéon, have begun this task.

One series of experiments, conducted with Roberta Kestenbaum and Debra Wein, used a habituation method to investigate whether infants apprehend the locations and movements of hidden objects in accord with the principle that objects move on spatiotemporally continuous paths (Spelke & Kestenbaum, 1986; Spelke, Kestenbaum, & Wein, in preparation). Four-month-old infants were presented with events involving objects that moved successively behind two spatially separated screens. The events were borrowed from Moore, Borton, and Darby (1978), whose ingenious studies of visual tracking revealed dramatic developmental changes, over the second half of the first year, in infants' patterns of looking at objects that move behind occluders. In the "continuous event," a narrow object moved in and out of view behind the separated screens; in the "discontinuous event," one object moved behind the first screen and after a pause, a second object emerged from behind the second screen (Fig. 6.16). These events are superficially similar; only the presence or absence of a visibly moving object between the two screens distinguishes them. Adults understand the events differently, however, reporting that one object participates in the continuous event and that two objects participate in the discontinuous event (Spelke et al., in preparation). This inference follows from the principle that objects move on continuous paths.

Three habituation experiments investigated how infants apprehend these events. In each experiment, one group of infants was habituated to the continuous event and one group of infants was habituated to the discontinuous event, and then all the infants were presented with events involving one or two objects with no occluders. The positions and movements of the test objects were varied in different experiments so that only the number of objects

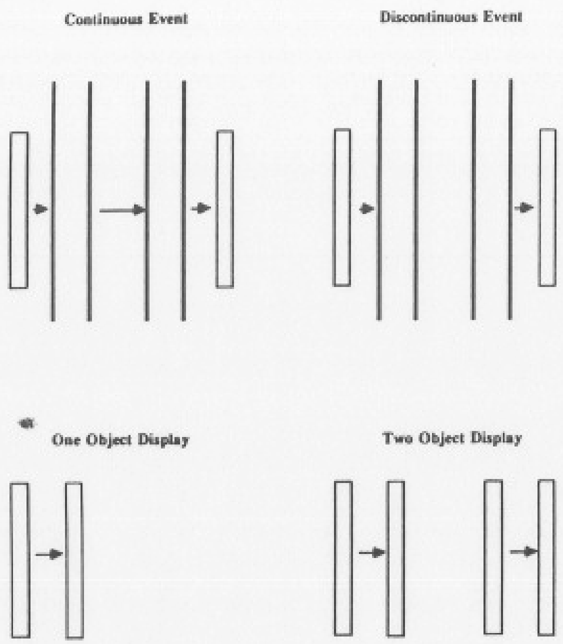

FIG. 6.16 Habituation displays (top) for three experiments on infants' understanding of continuous and discontinuous occlusion events. Test displays (bottom) presented one or two objects undergoing different motions in different experiments; the motion patterns for one of the experiments is indicated (from Spelke & Kestenbaum, 1986).

served as a consistent basis for generalizing habituation (see Spelke & Kestenbaum, 1986). The results of the studies were the same: Infants who were habituated to the continuous event generalized habituation to the one-object test display and looked longer at the two-object test display, whereas infants who were habituated to the discontinuous event did the reverse (Fig. 6.17). These looking patterns provide evidence that infants, like adults, understand the continuous event as involving one object and the discontinuous event as involving two objects. Infants apprehend these events in accord with the principle that objects move on spatiotemporally continuous paths.

Our next experiments focused on events in which objects disappeared behind one wide screen. In these events, one object moved toward the screen at a constant speed and disappeared behind it, and then a second visually indistinguishable object appeared at the opposite side of the screen, moving at the same speed. All that varied in these events was the occlusion time. In the constant speed event, the occlusion time corresponded to the time it would have taken one object moving at a constant velocity to traverse the region behind the occluder; in the too-fast reappearance event, the occlusion time was one third as long; in the immediate reappearance event, the second object began

to emerge from behind the screen as soon as the first object was fully hidden. Adult subjects reported that a single object participated in the constant speed and the too-fast events. They reported that two objects participated in the immediate reappearance event. Adults were less confident about all these judgments than they were when judging the continuous and discontinuous events from the first experiments (Spelke et al., in preparation).

To investigate how infants apprehend these events, separate groups of subjects were habituated to each of the three events and then all the infants were tested with events involving one versus two objects, without occluders. The visible velocities of the objects and the occlusion times were varied in two separate experiments so that only the number of objects provided a consistent basis for responding to the test events. Patterns of dishabituation did not differ across the three experimental conditions (Fig. 6.18). Unlike adults, infants do not appear to apprehend occlusion events in accord with the notion that objects move at constant (or gradually changing) speeds.

The conclusions we draw from these experiments are exactly opposite to those drawn by Moore et al. (1978) and Bower (Bower, Broughton, & Moore, 1971; Bower & Paterson, 1973). In their studies, young infants interrupted their visual tracking of objects if the objects appeared to move at changing speeds, but not if the objects appeared to move discontinuously. In view of our findings, however, it seems likely that these tracking patterns stem from properties of the eye-head movement system and do not reflect infants' apprehension of the numerical identity or distinctness of objects. If the head and eyes tend to move on relatively smooth trajectories, infants will have difficulty following an object if it suddenly changes speed. Such a deficiency

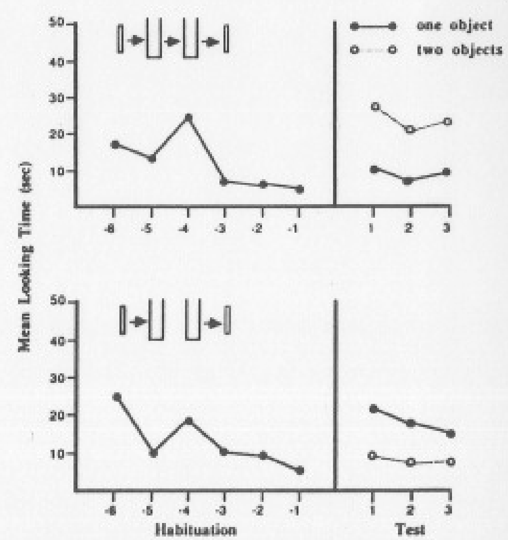

FIG. 6.17 Looking times to displays of one versus two objects after habituation to continuous or discontinuous occlusion events (from Spelke & Kestenbaum, 1986, Experiment 1).

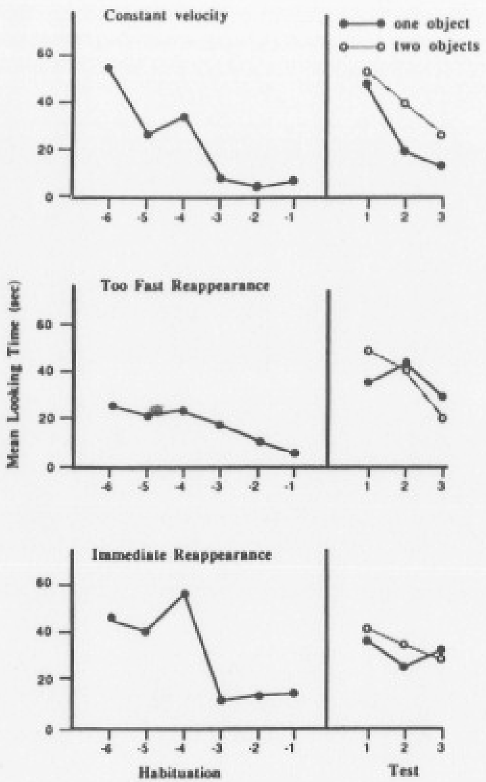

FIG. 6.18 Looking times to displays of one versus two objects after habituation to events in which an object disappeared behind a wide screen and reappeared after an appropriate time interval, an interval that was too short, or an interval that approached zero (from Spelke, Kestenbaum, & Wein, in preparation).

does not indicate that infants conceive of objects as entities that can only move at constant speeds, as Bower (1982; Bower et al., 1971; Bower & Paterson, 1973) suggested. Moreover, infants will track smoothly any movement at a uniform speed, whether or not that movement traces a connected path. This does not imply that infants understand both continuous and discontinuous movements as involving a single object.

In brief, young infants appear to apprehend events involving objects that move out of view in accord with the principle that objects are spatiotemporally continuous. This principle allows infants to trace the paths of objects through time and to infer how objects behave when they are fully occluded. Stronger evidence for the same ability comes from experiments by Baillargéon investigating whether infants understand occlusion events in accord with the principle that objects are substantial.

Baillargéon's first study focused on two events involving a stationary block and a rotating screen (Baillargéon, Spelke, & Wasserman, 1985). At the start of each event, the screen lay flat on the table and the block could be seen behind it. Then the screen began to rotate upward toward the block,

fully occluding it. In one event, the screen continued rotating until it reached the place where the occluded block stood; in the other event, the screen continued rotating through the place that the block had occupied until it lay flat on the table. Once the screen came to a halt in each event, it reversed its direction of rotation and returned to its initial position, revealing the object (see Fig. 6.19). Adults judge that the first of these events is expected and the second is impossible. These judgments follow from the principle that objects exist continuously in space and time (thus, the occluded block continues to exist behind its occluder) and the principle that objects are substantial (thus, the screen cannot pass through the place that the block occupies).

To investigate how infants apprehend these events, 5-month-old infants were first habituated to the screen with no object present, moving as it would later move in the impossible event. After habituation, the block was introduced and the two events were presented. Infants looked markedly longer at the impossible event, even though it presented a familiar motion (Fig. 6.20). The experiment provided evidence that infants understand occlusion events in accord with notions that objects are spatiotemporally continuous and substantial.

Further research by Baillargéon provides evidence that even 3- and 4-month-old infants understand the rotating-screen events as adults do (Baillargéon, in press a). Six- to 8-month-old infants respond appropriately to even more complex events involving an occluder, a moving object, and an occluded barrier in the path of the hidden object's motion (Baillargéon, 1986). In understanding such events, infants take account of the location, the orientation, and the size of both the hidden obstacle and the hidden or visible object that moves toward that obstacle (Baillargéon, in press b). For example, 7-month-old infants respond to a large rotation of a screen as impossible if a tall thin object stands behind the screen in a vertical orientation; if the same object is oriented horizontally, the infants appropriately treat the same rotation as a possible event.

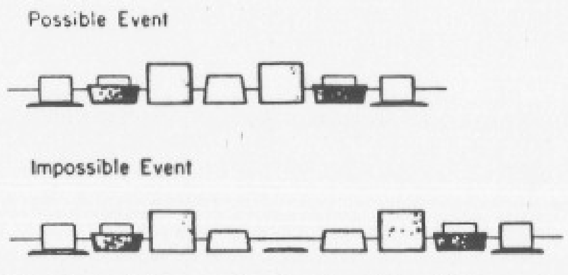

FIG. 6.19 Test displays for an experiment on knowledge of object persistence and substance (from Baillargéon, Spelke, & Wasserman, 1985).

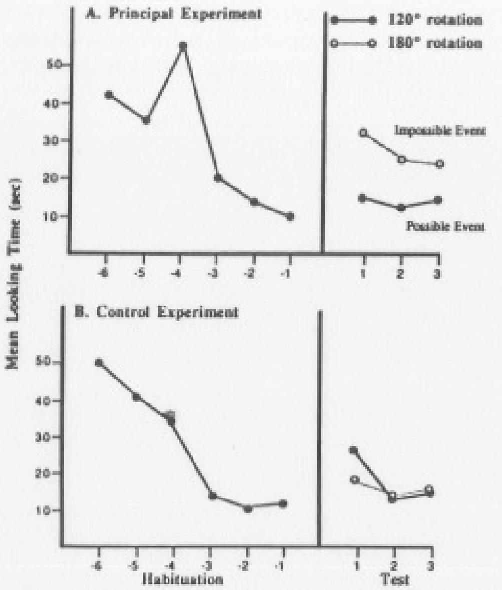

FIG. 6.20 Looking times to test events in which a screen rotated 180° or 120° through (a) location occupied by an occluded block or (b) an unoccupied location. The infants in both conditions were first habituated to the screen undergoing the 180° rotation. In (a), the 180° test rotation was impossible; in (b), neither rotation was impossible (from Baillargéon et al., 1985).

In summary, these experiments provide evidence that infants are able to make sense of their successive encounters with objects, keeping track of the existence and the movements of objects that are hidden. Like adults, infants appear to understand physical events as involving substantial entities that exist continuously. Infants would seem to appreciate two fundamental object properties, substance and spatiotemporal continuity, before they can search for objects that are hidden and even before they can reach for objects that are visible. Prior to the development of most object-directed actions, infants are endowed with mechanisms that carry them beyond the immediately perceivable world.

THE OBJECT CONCEPT

The findings of all the experiments described in this chapter can be explained by proposing that young infants have a fourfold conception of the physical world. Infants appear to endow the world with entities that are *cohesive, bounded, substantial,* and *spatiotemporally continuous.* Each of these properties is abstract: It cannot be seen or smelled or touched. These properties can be known, however, because each constrains how objects can be arranged and how they can move. Cohesion limits an object's movements to those that preserve its integrity: When objects move freely, they move as wholes. Boundedness limits an object's movements to those that preserve its

distinctness: Unlike water or mercury, objects do not blend into other objects when they are freely displaced. Substance restricts an object to movements through unoccupied places: When objects move freely, they do not pass through one another. Spatiotemporal continuity restricts an object to movements along connected paths: An object does not move from one place to another without tracing a continuous path between them.

Because these properties constrain the behavior of objects in space and time, infants can find objects by analyzing the perceived arrangements and motions of surfaces. That is why, I suggest, the infants in our experiments used the common and independent motions of surfaces to discover the unity and boundaries of objects in space, and also why they used the continuous and discontinuous motions of surfaces to discover the identity and distinctness of objects through time. Because an object's properties determine its behavior, infants can also predict the future state of an object under certain conditions. Thus infants predict that an object will stop moving when it arrives at a place occupied by a second object.

The properties of unity, boundedness, substance, and spatiotemporal continuity appear jointly to constitute an initial *object concept.* Although this concept is less rich than our conceptions of objects as adults, it may constitute the core of those conceptions. Adults come to believe many things about the behavior of objects, some of them idiosyncratic and incorrect (e.g., Gentner & Stevens, 1983), but everyone seems to believe intuitively that objects move as cohesive and bounded bodies on continuous paths through unoccupied space. We believe these things so strongly that we hesitate to consider something a physical object if its parts are scattered around a room, if it appears in different places without ever moving between them, or if other solid bodies can pass through it. Learning may enrich human conceptions of objects, but learning does not appear to overturn the conceptions humans hold as infants.

PERCEPTION AND THOUGHT

The proposal that infants apprehend objects by virtue of an object concept raises old and difficult questions about the distinction between perception and thought. Intuitively, these activities seem to differ greatly: *Perceiving* that a tree is green is different from *thinking* that it is in the state of New York; *perceiving* that the shape of some cookies is round is different from *thinking* that their number is prime. But how do these activities differ, and where is the boundary between them? Intuition does not provide ready answers to these questions.

One traditional attempt to distinguish perception from thought relies on introspection. Both structuralist and gestalt psychologists suggested that perceptual processes are opaque to consciousness and give rise to immediate and vivid impressions of the surrounding world. In contrast, processes of thought were said to be relatively slow, deliberate and transparent, yielding fainter impressions that bear the traces of the reasoning behind them. Insofar as introspection is a guide, however, the identification of thought with deliberateness and transparency to consciousness appears to be wrong. Numerous experiments suggest that central cognitive systems can be as opaque as perceptual systems and can give rise to experiences that are as immediate and unanalyzable (Humphrey, 1951, discusses some examples). It is not surprising, therefore, that introspective methods have failed clearly to distinguish perception from thought.

A second, related proposal is that mechanisms of perception are distinguished from mechanisms of thought by their degree of autonomy: Whereas central cognitive systems are open to the influence of what we believe, perceptual systems are "impenetrable" by explicit knowledge and thought (Fodor, 1983; Pylyshyn, 1980; see also J. J. Gibson, 1966, 1979; Helmholtz, 1924; Michotte, 1963). Distinguishing perception from thought on this basis raises the considerable practical difficulty of determining whether a given system has been penetrated, in its operation, by belief (see Fodor, 1983). Insofar as the penetrability of a system can be determined, however, mechanisms of thought appear to be as impenetrable as mechanisms of perception. Studies of intuitive reasoning about geometry and physics provide examples. One may learn in school that space is non-Euclidean and is furnished with particles that move discontinuously. Despite this learning, humans appear to continue to experience a Euclidean world of spatiotemporally continuous matter and objects (see Gentner & Stevens, 1983, for other examples of students' resistance to certain scientific theories; see Cheng, 1986, and Cheng & Gallistel, 1984, for an extended demonstration of the modularity of spatial knowledge in the rat). The current attempt to distinguish perceiving from thinking on grounds of cognitive penetrability will fail, I believe, as did its predecessor.

At least four other distinctions between perception (or more narrowly, "sensation") and thought (or "judgment") have been suggested: (a) perception is partly innate whereas thought depends wholly on learning (e.g, Helmholtz, 1924); (b) perception is "passive" whereas thought is "active" (e.g., Piaget, 1969); (c) perception is "direct," involving no intermediate representations, whereas thought depends on representations and rule-governed inferences (e.g., J. J. Gibson, 1966, 1979); and (d) perception is relatively simple whereas thought is complex: It requires more of the brain, it is beyond the capacities of lower animals, and so forth (see Fodor, 1983). Although these suggestions cannot be evaluated adequately, all of them appear to be wrong. Thought, like perception, appears to be innately based (e.g., Antell & Keating, 1983). Perception, like thought, appears sometimes to be active (e.g., E. J. Gibson, 1970), representational (e.g., Marr, 1982), and dependent on mechanisms of considerable complexity (e.g., Rock, 1984). Perceptual and cognitive mechanisms both give sense to the world, and they appear to grow and to operate in similar ways.

If perception can be distinguished from thought, I suggest it is because human perceptual and cognitive systems take different kinds of input and bring different kinds of sense and order to experience. Human perceptual systems appear to analyze arrays of physical energy so as to bring knowledge of a continuous layout of surfaces in a state of continuous change. We perceive the layout and its motions, deformations, and ruptures. This continuous layout contains no spatially bounded "things" and no temporally bounded "events": Perceptual systems do not package the world into units. The organization of the perceived world into units may be a central task of human systems of thought. Different systems of thought seem to specialize in units of different kinds: They cut up the world in different ways for different purposes. All cognitive systems seem to function, however, to divide the continuous perceived world into things.

My research has concerned one kind of entity that a central cognitive system appears to find in the world: physical bodies. Other cognitive systems may find entities of other kinds. For example, *events* may be known by virtue of systems of thought. Our conceptions of the world may lead us to break the constantly changing layout into units such as a greeting (defined in part by the actor's intentions), or a battle (defined in part by geographical and political arrangements). As further examples, students of physics or biology develop theories that carve the world into such entities as particles and cells (see Jacob, 1973; Kuhn, 1962), and children and adults develop systems of mathematical thought that find in the world such entities as classes (with numerical properties) and paths (with geometric properties). Paths form part of the layout that children perceive; even infants can see the ground that extends in front of them, and this perception can guide behaviors such as locomotion (E. J. Gibson & Walk, 1960). Perception of the layout, however, does not bring knowledge of paths as geometric objects whose properties allow one to determine which of several routes to a goal is the shortest and how the layout is arranged beyond one's view. The parsing of the world into things may point to the essence of thought and to its essential distinction from perception. Perceptual systems bring knowledge of an unbroken surface layout in an unbroken process of change. Conceptual systems organize that layout into things whose properties and relations specify where each begins and ends, both within and beyond the immediately perceivable world, and how different things are related to one another.

The notion that perception brings knowledge of a continuous and continuously changing layout seems to me implicit in the work of J. J. Gibson (1950, 1966, 1979), whose attempts to develop a theory of perception as unmediated by thought focused on perception of the layout and of the continual, unbounded happenings within it. This same notion is raised explictly by Marr (1982), who suggested that the representation of the surface layout (his "2½-d sketch") "marks the end, perhaps, of pure perception" (p. 268). The notion that thought begins with a continuous universe and carves it into things seems to lie behind certain analyses of scientific thought, in which theories are said to divide the world into objects (e.g., Jacob, 1973; Kuhn, 1962; Quine, 1960) and some analyses of commonsense thinking as well, in which notions about certain kinds of objects are said to provide the conditions for singling out those objects (e.g., Wiggins, 1980). With this distinction between perception and thought, it may be possible to hold simultaneously to two theses that seemed incompatible: the thesis that observing the world is different from theorizing about it, and the thesis that theories about the world determine the objects that are "observed" to inhabit it. By granting, further, that both perception and thought are innately based, it may become possible to envisage how different people could come to develop similar theories; indeed, how any person could develop any theory at all.

What then are concepts? I suggest that concepts are best understood in terms of the work of organizing the perceived world into units: They correspond to those entities into which systems of thought divide the world. To have a concept "object," "oxygen," "three," or "triangle" is just to have a central mechanism that carves the perceived world into physical bodies, molecules, sets, or geometric forms. Although this notion leads in a circle, it may give some sense to the claim that concepts are the inhabitants of theories (e.g., Carey, 1985; Keil, in preparation; Kuhn, 1962) while leaving open certain issues about the nature of concepts that are best not prejudged, such as whether concepts can be innate, or not expressible through language, or unconscious, or found in lower animals. The object concept, on this view, arises from an intuitive theory of the physical world and its behavior. It is present, albeit in impoverished form, near the beginning of life. Its emergence does not depend on language, on sensorimotor activity, or on associative learning. It reveals itself through the ways infants organize and make sense of the world they perceive.

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