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COGNITION IN INFANCY

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1. Forward

This paper is concerned with some of the central conceptions about the world that we hold as human adults. I will attempt to bring some of our mature conceptions to light by discussing a variety of experiments on the cognitive abilities of young human infants.

The enterprise of studying infants in order to learn about adults may strike the reader as bizarre, for infants are frustrating subjects to study. A young infant can do very little. Infants do not reach for and apprehend visible objects until they are about 4 1/2 months old, they do not sit independently until about 6 months, and most do not begin walking or talking until the second year. Young infants also give us scant reason to suppose that they know much about the world. They seem to know little about the characteristic behavior of the particular kinds of objects that surround them, like balls and rattles. They certainly are ignorant, moreover, of the structure of most of the events and activities that will occupy their time, like television programs and eating dinner.

Nevertheless, infants have two related capacities that make them very interesting subjects for any student of human cognition: Infants are built to explore and to learn. From the start of life, infants attend to objects and events very systematically, and they quickly develop a wealth of knowledge about the world. In our infancy and early childhood, humans learn about many kinds of objects: their characteristic properties, their behavior, and their functions. We learn about people: their actions, their predilections, and the nature of the social exchanges they engage in. We learn how to count and how to catch a ball by extrapolating its trajectory through the air. This learning occurs spontaneously, moreover, with no instruction. No one explains to a child what a cup is, or what people are like, or how objects move.

Because infants learn so rapidly, spontaneously, and systematically, it seems likely that they come to the world with certain conceptions of what they will find to explore and learn about. Initial conceptions about objects and events might lead infants to interpret their experience in ways that promote rapid learning about those objects and events. If initial conceptions do underlie our earliest exploration and learning, those conceptions should determine, in large part, both the shape and the substance of the knowledge that we acquire.

These conceptions, therefore, are likely to remain at the center of our thinking. By studying infants, psychologists may be able to peel away the layers of specialized notions that humans acquire and to see more clearly the core conceptions that we hold.

2. Material objects

To illustrate this possibility, the present paper will focus on just one conception that appears to begin in infancy: the concept of a material object. As adults, we tend most readily to understand the world in terms of things like cups and cars, not in terms of parts of things like the surfaces of cars, or ensembles of things like cars-and-their-respective-owners, or stages of things like cars-just-whenever-they-are-in-garages. These things--the cups and the cars--exemplify what will here be called "objects." Our focus on objects is revealed dramatically in visual perception. When we as adults look at any scene, the shapes and the boundaries of the objects in the scene are given only very indirectly in the light that meets our eyes. Every object is adjacent to other things, and every object is partly hidden: its back is hidden by its front, and some of its forward surfaces are usually hidden as well. But we do not experience an arrangement of visible fragments of surfaces, despite these patterns of adjacency and occlusion. We organize the scene into an arrangement of complete, solid, and bounded objects.

Our focus on objects is also revealed in other ways. Objects are what we communicate about most readily when we talk about parts of the physical world, and they are what we tend to count. If someone points to a cup, for example, and says "I like this" or "this belongs to Julia," these statements are of course ambiguous: "this" could be the cup, its handle, the pattern on its surface, the stuff it is made of, or the entire set of china of which it is a member. Similarly, if someone asks us to count the contents of a pocket, we can in principle count any number of things, such as five coins, ten coin faces, or two kinds of metal. In practice, however, we are rarely troubled by these ambiguities. In the absence of information or instructions to the contrary, we will focus on the cups and the coins: the objects.

Finally, our focus on objects is revealed by the ways in which we trace parts of the world through time. Our world is composed of persisting things that exist continuously, even though our encounters with these things are sporadic. Somehow, we can apprehend the enduring nature of the objects we have encountered on several occasions. We can also predict, to some extent, what will happen to these objects in the future.

The tendency to focus on objects is discernible quite early in childhood, and it seems to develop spontaneously, without teaching. Objects are what children are apt to communicate about and learn words for: they focus on the tables and not on the table-legs or table-stages. Objects are also what children spontaneously count, when they begin counting in the third or fourth year. Thus, it seems reasonable to suppose that some of our conceptions of objects begin at the beginning of infancy and guide the development of knowledge.

What are the conceptions of objects that we hold as adults, which could be shared by human infants? For one, adults seem to conceive of the world as composed of things that are relatively uniform in their substances and shapes. This conception may lead us to perceive objects by grouping together surfaces of the same color and texture, surfaces with aligned edges, and surfaces that together form a unit with a regular shape. Second, adults seem to conceive of the world as composed of things that are spatially connected. This conception may lead us to perceive objects by detecting the three-dimensional arrangement of surfaces in a scene, grouping together all and only surfaces that are touching. Third, adults evidently conceive of the world as composed of things that are separately moveable and that move as wholes: things that persist as connected units over their free movements. This conception may lead us to divide unfamiliar scenes into objects by moving surfaces about and observing which surfaces move together.

Further conceptions concern the kinds of movements that objects undergo. We as adults believe that objects move continuously through space and over time: an object cannot jump from one place to another. Moreover, we expect each object to move in a certain smooth trajectory, as long as it does not hit any other object. Third, we believe that two distinct objects cannot occupy the same place at the same time. If two objects collide, one or both of them must give way and change its path of movement, at least. These notions about the behavior of material objects help us to predict the future states of an object and to

represent the object and its location when it is out of view: we expect objects to persist as connected units whenever they move freely, without contacting other things. These notions also help us to trace objects through time: We will not grant that we have encountered a single object, on two different occasions, unless there is a continuous path on which the object could have traveled from the first encounter to the second.

In addition to these general conceptions, adults have many specific conceptions about objects of particular kinds. We evidently conceive of the world as composed of particular sorts of things, each with its characteristic properties, functions, and life-history. These conceptions can also guide our apprehension of the objects around us. Once we have recognized that an object is a cup, for example, our knowledge about the properties of cups will lead us to see the object as separate from the saucer beneath it. Our knowledge of the behavior of cups will also lead us to predict what will happen to the object if it is dropped or filled with tea.

Our conceptions of objects usually work together: Things of known kinds tend also to be relatively regular in color, texture, and shape, they tend to be spatially connected and separately moveable, and they tend to move continuously and only through space not occupied by other objects. But our conceptions do not always agree, and where they conflict, our intuitions about objects can become unclear. What are we to make of a book in three volumes: is it one object or three? What of the wheel of a bicycle: is it an object or only part of an object? If human adults have a core conception of objects which gives a determinate answer to these questions, our introspections certainly do not seem to reveal what it is. Indeed, the apparent vaguenesses and confusions in our thinking about objects have led some to propose that humans have no general conceptions of material objects at all (Hume, 1738/1962; Geach, 1962; see also Wiggins, 1980). This conclusion, however, could be wrong. We as adults might have a core conception of objects that guided the development of all further conceptions. If such a conception exists, then studies of infants might reveal what it is.

3. The origins of conceptions of objects

The possibility that infants share any of our conceptions is rarely considered seriously. In developmental psychology, a field shaped both by Empiricist and by Piagetian theory, most investigators believe that conceptions of material objects are constructions. These conceptions are thought to be achieved slowly over the first years of life, as children discover certain regularities among their sensations and their actions (see Helmholtz, 1885/1925; Piaget, 1937/1954. For a recent statement of this position, see Harris, 1983). Newborn infants, on this view, cannot perceive or know objects. They experience only sensations of various qualities, produced by patterns of light, sound, pressure on the skin, and other stimulations.

Only the Gestalt psychologists have proposed that humans have an initial ability to perceive objects. Like the Empiricists, however, they denied that infants have conceptions about the things they perceive. On the Gestalt view (see Koffka, 1935), perception of objects is not guided by conceptions of any kind; the experience of a world of objects arises automatically as a consequence of certain organizing forces in the nervous system. These forces lead humans, even as infants, to structure visual arrays into units with symmetrical shapes, uniform colors, and a common pattern of movement (Wertheimer, 1923/1958). But conceptions of objects were thought to develop later, on the basis of this initial, automatic perceptual tendency.

Nevertheless, this paper will explore the view that human infants and human adults share a core conception of the material world. There is a conception of objects, I propose, that is present throughout life and that serves as a basis for acquiring knowledge. Four lines of research will be described, each probing some aspects of that conception.

4. Overview of the research

This research was conducted in collaboration with Renee Baillargeon, Philip Kellman, Penny Prather, Hilary Schmidt, and Nancy Termine at the University of Pennsylvania, and with Claes von Hofsten at the University of Minnesota. We have focused on infants' abilities to perceive objects, to act on objects, and to follow objects through time. Specifically, our experiments investigate whether infants ever know if and how a visible object continues

behind a second object that partly hides it, whether infants can ever determine if two adjacent surfaces lie on the same object or on distinct objects, whether infants take certain parts of the visual world to be countable and independently manipulable--and if so, what parts--and whether infants appreciate that certain parts of the world persist as units when they move freely, even if they move fully out of view. Answers to these questions, we hope, will suggest what the infant's conceptions of objects are.

5. Perceiving partly occluded objects

I will begin by asking whether infants can ever perceive the complete shapes of objects that are partly hidden. Consider a regular, three-dimensional object like the rod depicted in Figure 1: an object whose center is occluded by a nearer object but whose ends are visible and move together rigidly, back and forth behind the occluder. As adults, we infer that these ends are connected behind the occluder. This inference could be guided by the notion that arrangements of objects tend to be simple and regular. Since the two ends of the rod are of the same color and texture, are aligned, and can be joined to form a relatively simple figure, we may infer that they lie on a single object. This inference could also be guided by the notion that separate objects tend to move independently of each other, each object moving as a whole. Since the two ends of the rod move in a common rigid translation, we may infer that they are connected behind the occluder.

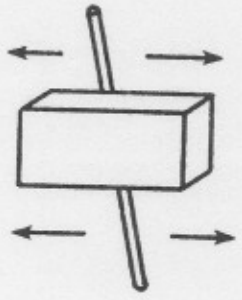


Figure 1. Arrows indicate the path of motion.

Do infants perceive the ends of this object as connected? To address this question, we have conducted an experiment with 4-month-old infants--infants just below the age when they begin to reach for things (Kellman and Spelke, in press). Like many other studies of infant perception, this experiment relied on an exploratory pattern that infants exhibit very consistently. If a display is shown to infants repeatedly, they tend to look at it less and less over these successive presentations; if something new is then presented, their looking time usually increases. The amount of increase in looking time to the new display appears to be a function of the perceived similarity of the new display to the old: if infants are presented with two new displays, they often look more to the display that differs more from the original display. In our experiment, accordingly, infants were presented with a moving black rod, partly hidden behind a stationary tan block, on a series of trials. Each trial lasted as long as the infant looked at this display, and it ended when he or she looked away. These presentations continued until the infant's looking time per trial had declined to half its original level; this usually occurred after infants had looked at the rod and block display for about three minutes. Then the occluder was taken away, and infants were shown two different displays on alternating trials: the single, complete rod that adults perceive, and two rod pieces that matched the visible areas of the original partly hidden object (see Figure 2). Infants were expected to look longer at whatever new display appeared more different from the original display. If they perceived the moving rod as complete, they should have looked more at the broken rod. If they perceived only an arrangement of visible surfaces in the occlusion display, then they should have looked more at the complete rod, since the same rod surfaces were visible in the broken rod display and the occlusion display.

The results were clear: infants looked rather little at the complete rod when it was presented. They looked four times as long at the broken rod. This difference did not reflect any intrinsic preference for the broken rod; in other subsidiary experiments, we found that infants look at complete and broken rods about equally when they are equally familiar. It seemed, then, that the infants had originally perceived the moving rod to continue behind the occluder. When the occluder was taken away, they recognized the complete rod as familiar and perceived the two rod pieces as novel, even though these pieces corresponded to the visible areas of the original, partly hidden object.

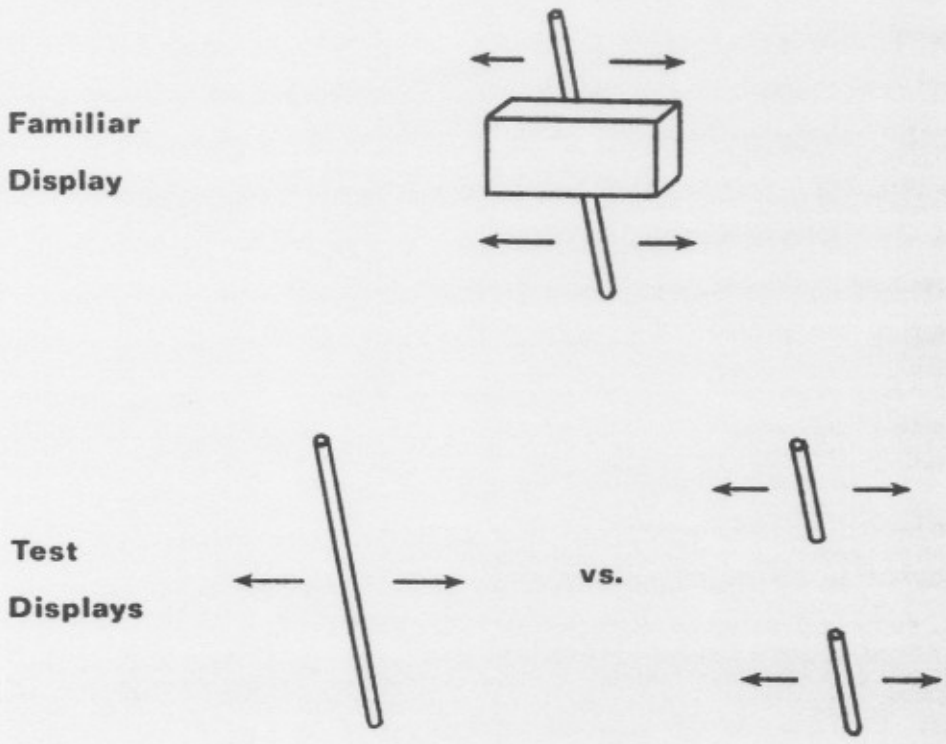


Figure 2

This finding provides evidence that infants can perceive partly hidden objects. It is possible that this ability follows from an initial conception of objects. In particular, infants' perception of the complete rod might have depended on the conception that objects tend to be regular in shape and substance or on the conception that objects tend to be connected and separately moveable. To begin to distinguish these possibilities, we have conducted experiments in which we presented 4-month-old infants with a variety of stationary objects of regular shapes.

In one experiment (Kellman and Spelke, in press), infants were presented with the rod in Figure 1, now stationary and centered behind the block. Adults perceive a unitary, connected rod when they view this display. After infants became familiar with the partly hidden rod, they were tested with stationary complete and broken rods. The results of this experiment surprised us. After infants became familiar with the partly hidden rod, they showed renewed interest in both the broken and the complete test rods, and they looked at these objects equally. Since these infants were interested in the broken rod, we have further evidence that

they did not perceive the partly hidden rod to end where its occluder began. But since the infants were also interested in the complete rod, we have evidence that they did not perceive the ends of the partly hidden rod as connected behind the occluder. Their perception seems to have been indeterminate.

In subsequent experiments (Kellman and Spelke, in press; Schmidt and Spelke, 1983a), infants were shown objects with more regular forms: for example, a triangle made of rods, an extended, textured flat surface, a three-dimensional solid sphere, and a solid cube (see Figure 3). Adults perceive regular, connected objects when they view each of these displays. In contrast, infants appeared not to perceive either a unitary, connected object or two visible surfaces separated by a gap. Further studies have indicated that infants do pay attention to these partly hidden stationary objects, and they perceive the visible ends of these objects quite well (Kellman and Spelke, in press). Nevertheless, infants do not perceive each object as a connected unit that continues in places where it is hidden.

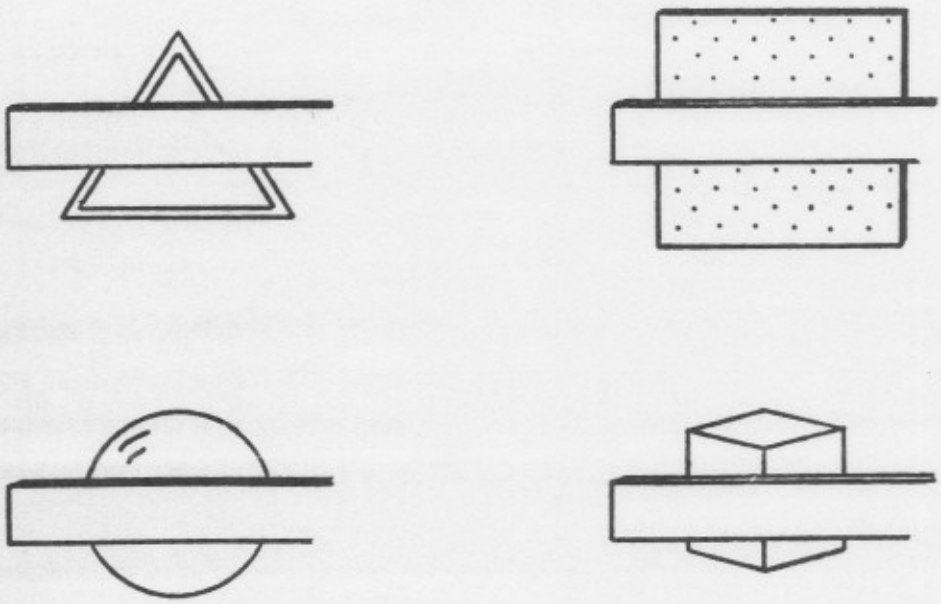


Figure 3

This finding has now been bolstered by several other experiments. For example we have conducted studies using a new method, designed to tap infants' immediate impression of a partly hidden object (Schmidt and Spelke, 1983b). Infants were allowed to look at a partly hidden object, such as the sphere in Figure 4, for about 5 seconds. Then the occluder was removed before their eyes, revealing either a complete sphere or a broken sphere (see Figure 4). If the broken sphere looked novel or surprising, infants should have looked longer at it. But they did not: infants looked equally at the complete and broken objects.

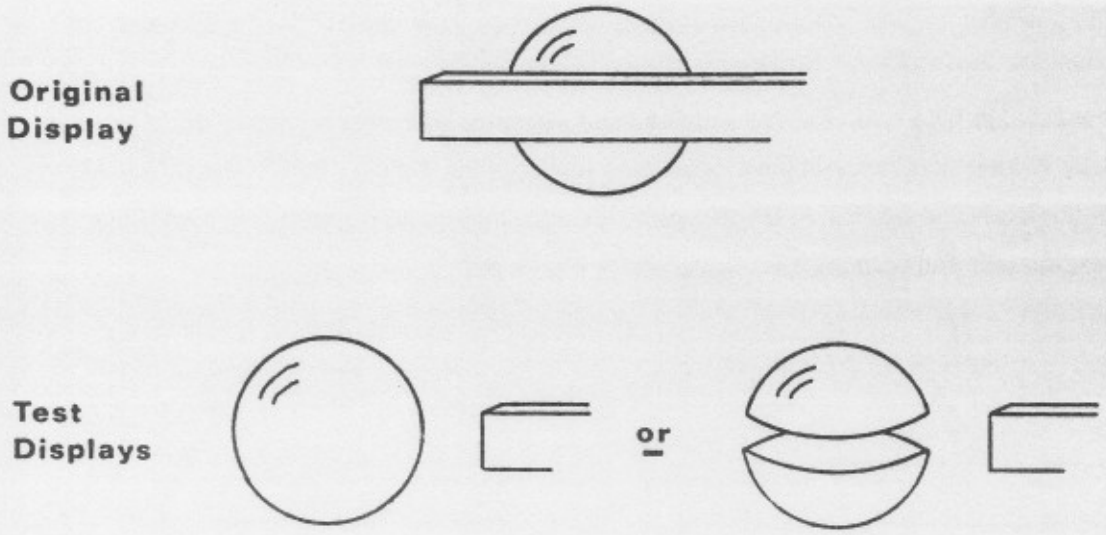
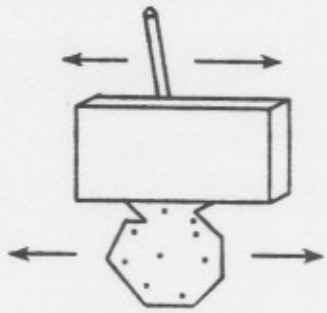


Figure 4

Furthermore, we have investigated whether the simplicity and regularity of a moving object influences infants' perception of its boundaries (Kellman and Spelke, in press). Infants were presented with the display depicted in Figure 5: a rod and a polygon of different colors, textures and shapes that moved together behind an occluding block. Then the infants were tested with a connected object composed of these surfaces and with a broken object (see Figure 5). When adults viewed this display, they reported a weak impression that the rod and polygon were connected--a much weaker impression than in the case of the moving rod or even the stationary rod. If simplicity and regularity of color and shape have any effect on infants' perception, then we expected infants also to perceive these surfaces as less strongly connected than the ends of the moving rod. In fact, however, the static configurational properties of this display seemed to have no effect on infants' perception. After infants

became familiar with this display, they showed little interest in the connected object, and they looked much longer at the broken object. Infants' preference for the broken display was as strong in this experiment as in the experiment with the moving rod. Thus, infants appeared to perceive the moving rod-and-polygon as a connected object--an object as unitary as a moving rod.

Familiar Display



Test Displays

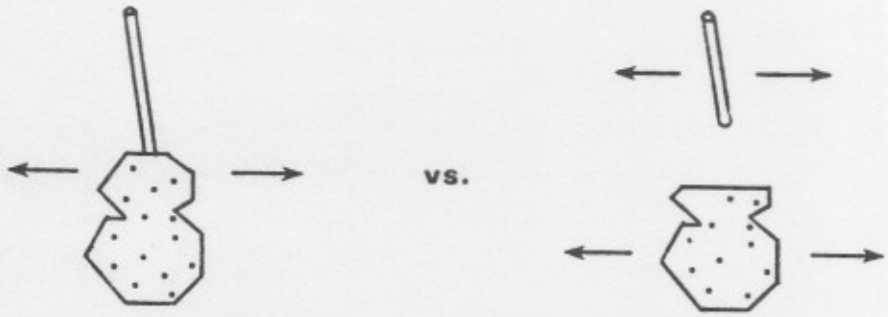


Figure 5

These experiments, taken together, suggest that infants do not perceive in accordance with the notion that objects tend to be simple and regular in their shapes and colors. They also suggest that infants do not perceive objects by virtue of the automatic organizational tendencies that the gestalt psychologists described.

Since movement seems to have a big effect on perception of partly hidden objects, we have gone on to investigate infants' perception of objects that move in different ways. Briefly, it seems that any translation of an object in three-dimensional space has the same effect on infants' perception. For example, infants perceive the unity of a partly hidden object that moves only in depth, toward and away from themselves and from the occluder (Kellman and Spelke, 1983). It is necessary, however, that the object and its occluder move independently. If infants are presented with a rod and block that move back and forth together, they do not appear to perceive a unitary rod (Kellman and Spelke, in press). It seems likely that in this case, infants perceive the rod and the block as a single unit. The common movement of the rod with the block may lead infants to perceive the rod-and-block as one connected object, just as the common movement in the earlier studies led infants to perceive a unitary, connected rod.

The results of these studies shed light, I believe, on the original questions about infants' conceptions of objects. First, they provide some evidence against the view that humans begin life by experiencing only sensations produced by the visible surfaces of things. In particular, they provide evidence against the claim of Piaget, and some empiricists, that the ability to perceive objects as continuing where they are hidden depends on the developing coordination of action. A four-month-old infant cannot act on objects in any very systematic way. If an object is placed within reaching distance, he can only swipe at it and flail about, contacting it rarely and by accident. If an object is placed in his hand, he can only clutch at it reflexively--he does not finger it, turn it around, or otherwise explore it. According to Piaget, infants of this age lack virtually all the sensory-motor coordinations that might provide a basis for perceiving and knowing objects. Nevertheless, infants seem to perceive objects under certain conditions, and they never seem to perceive a scene as a mosaic of visible fragments of surfaces. In no study did infants treat a partly hidden object as similar to a display that matched its visible surfaces. The ability to perceive objects seems to have emerged before the child's actions on objects have made many significant advances.

The studies also provide evidence against the Gestalt approach to object perception. To be sure, one could describe the results of our experiments in the language of Gestalt psychology, using the well-known Gestalt principles of organization (Wertheimer, 1923/1958). Infants could be said to perceive in accordance with the principle of common fate, which

dictates that surfaces go together if they move together, and not in accordance with the principles of similarity, good continuation, and good form, which dictate that surfaces go together if they are of the same color and texture, if their edges are aligned, or if they can be joined to create regular figures. But this formulation misses the central claim of Gestalt theory. To the Gestalt psychologists, the various principles of organization are diverse surface manifestations of a single perceptual tendency toward simplicity and regularity. Our experiments provide evidence that infants seek simplicity of some kinds but not of other kinds, and this finding calls into question the entire Gestalt analysis of object perception and its development. No general tendencies toward simplicity and regularity of form seem to underlie our first apprehension of objects.

These experiments are consistent with the view that infants perceive objects by virtue of a conception of the world and its organization. Infants might perceive as they do because they conceive of the world as composed of connected bodies that are independently and coherently moveable. When an object moves as a unit behind an occluder, this conception could lead infants to infer that the visible surfaces of this object lie on a single, connected body.

One may question, however, how strongly the experiments support this conclusion. We have shown that infants perceive the boundaries of objects under certain conditions, but must this perception follow from any conception of the world? Perhaps object perception depends, instead, on some mechanism specific to vision: a mechanism that analyzes patterns of occlusion and of motion, and that connects any partly occluded surfaces that move together. Such a mechanism would be interesting in its own right, but it need not spring from any more general understanding of the world.

It is possible to test these two interpretations by conducting further studies of the conditions under which infants perceive objects, of the ways in which infants act on objects, and of the predictions infants make about each object's future course. In different experiments, therefore, infants have been presented with objects in a variety of configurations, and a variety of their reactions to these objects have been measured. A few of these studies are described below.

6. Perceiving adjacent objects

Consider first how infants perceive objects in displays that involve no movement, in which two objects are either touching or are separated in depth (Figure 6). When infants perceive an arrangement of stationary surfaces that are touching, they might, by default, perceive these surfaces as connected to each other, thus comprising a single object. This default option would allow infants to perceive the boundaries of many objects correctly; without it, infants could never perceive the unity or boundaries of any stationary object. It would, however, lead to certain errors. Infants would perceive a single object even when contiguous surfaces belonged, in fact, to two distinct objects that were touching. They would perceive two adjacent objects as one unit even if the objects differed in color and shape, since infants do not perceive objects by grouping together surfaces into units with simple shapes and homogeneous colors. Two unfamiliar objects would always be perceived as a single unit if they were adjacent and unmoving.

Figure 6

Infants should perceive two stationary objects differently when the objects are separated in depth, however, if they conceive of the world as composed of units that are spatially connected. Infants might perceive two such objects as distinct, since they can see that the sides of the nearer object end before the front of the farther object begins. Alternatively, infants might not perceive the objects either as definitely connected or as definitely distinct: this display might be ambiguous for them, since they cannot move around the display far enough to see whether the objects have any hidden connection between them. In either case, the two objects should be perceived differently when they are separated in depth than when they are adjacent.

In one set of studies, we have investigated infants' perception of these displays by focusing on their ability to enumerate objects, asking how many objects infants perceive when two objects are adjacent or are separated in depth. Experiments in several laboratories now provide evidence that infants are sensitive to the number of items in a visual pattern or the number of events in a stream of sound, provided that the number is small. If infants are familiarized with a series of displays consisting of three dots in various configurations, they will subsequently show little interest in new configurations of three dots, and they will show renewed interest in configurations of two or four dots (Starkey and Cooper, 1980; see also Starkey, Spelke and Gelman, 1980; Strauss and Curtis, 1981). Infants will also respond to numerical correspondences across modalities in a striking way. If a visual display of two items and a visual display of three items are placed side by side while a sequence of two or three sounds is played, infants will tend to look at the display whose items correspond in number to the number of sounds (Starkey, Spelke and Gelman, in press).

We are using both these methods to investigate whether infants perceive one unit in a display of adjacent objects and two units in a display of spatially separated objects. One experiment (Prather and Spelke, 1982) used the same familiarization method as the earlier studies. Three-month-old infants were familiarized with a series of displays containing blocks of various sizes and colors, in various positions. For half the infants, each display contained only one block; for the others, each display contained two blocks that were visibly separated in the frontal plane (see Figure 7). Then all the infants were presented, for the first time, with the adjacent blocks and with the blocks that were separated in depth. We found that infants who had become familiar with one-block displays showed little interest in the adjacent blocks and looked longer at the blocks that were separated in depth. Infants who had become familiar with two-block displays did the reverse: they showed little interest in the spatially separated blocks and looked longer at the adjacent blocks. The experiment suggests that the infants perceived the adjacent blocks as one unit and the blocks separated in depth as two units.

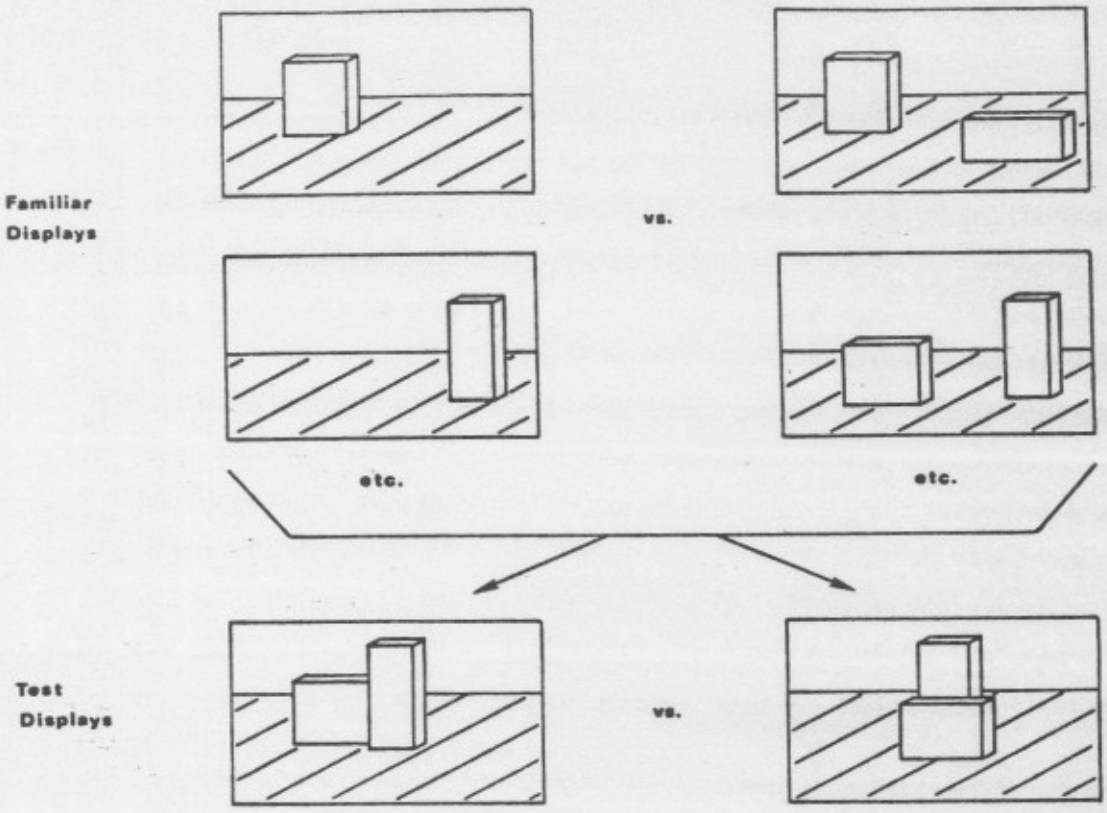


Figure 7

This study provided further evidence that infants perceive objects in accordance with the notion that objects are spatially connected, and not in accordance with the notion that objects are relatively regular in shape. Moreover, the study provided evidence that infants take the objects they perceive to be countable. This need not have been the case. Infants who encountered a visual scene might have organized that display into objects, and yet they might have counted other features of the scene, such as surfaces, colors, or corners. Nevertheless, infants seem to count the objects they perceive.

In the next set of experiments (von Hofsten, 1983; Spelke, 1983), we turned from studies of counting to studies of reaching and manipulation. We asked whether infants attempt to manipulate surfaces in the layout by reaching for the boundaries of objects. We studied infants just at the time at which they begin to reach effectively--about 5 months--and we observed their patterns of reaching for adjacent and spatially separated objects. Infants were presented with the two displays on Figure 8. Each display was composed of rectangular solid objects of the same color and texture. In one display, the front object was about 1" thick and

was placed flush against the other object. An adult can readily see that the two objects are touching by moving his or her head very slightly in any direction. The other display looked the same as the adjacent display from the front, but the nearer object was much thinner, and it was separated from the back object by a gap. The dimensions of the front object and the gap were such that the total depth of this display was the same as that of the adjacent display. Once again, the slight head movements that occur when adults or infants view anything will reveal this discontinuity in depth. (As the figure shows, the thin object actually is attached to the other object by a narrow support. This support was never visible from the infant's position.)

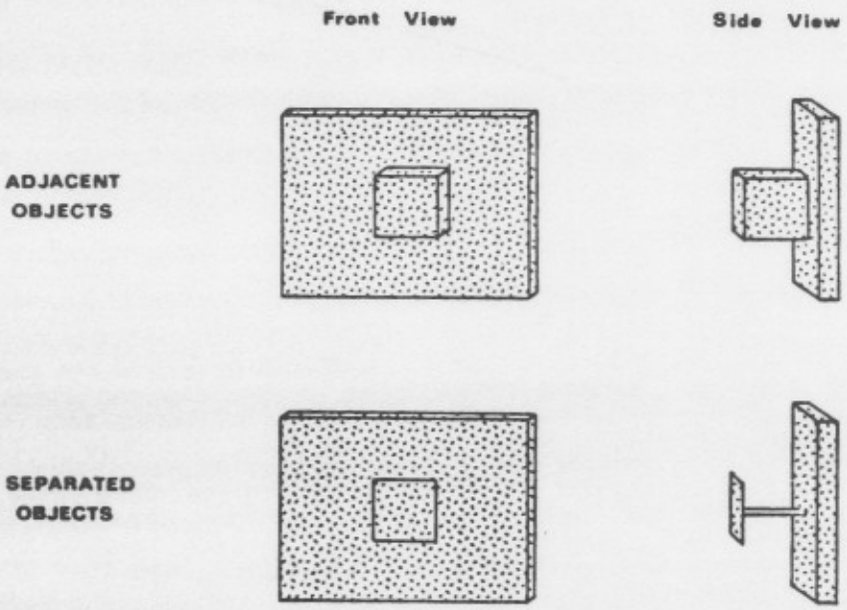


Figure 8

In the first experiment, the objects in these two displays were stationary, and they appeared on a series of alternating trials. The infants' patterns of reaching for these displays were systematically affected by the spatial relationship of the two objects. When the infants were presented with the objects separated in depth, they tended to reach for the little object, either without touching the other object at all or by only leaning the base of the hand against

the other object for support. When the infants were presented with the adjacent objects, however, they seemed to reach for the configuration of two objects as a whole. Sometimes infants reached only for the edges of the larger and more distant object with one or both hands; at other times, they reached with their fingers spread apart so as to encompass both objects at once. These patterns provided evidence that infants perceived the adjacent objects as one connected unit and the spatially separated objects as two distinct units. What is more, the experiment suggested that the infants did not perceive these units as disembodied regions of the visual field, but as things that could be manipulated as well as seen.

The next experiments investigated how movement affects perception of two adjacent objects. If infants have the notion that each object in a scene will move as a whole, then they should perceive two adjacent objects as distinct when one moves relative to the other: The presence of relative motion should overcome the default tendency to perceive two such objects as connected. This prediction was tested with further studies of reaching. In one study, the adjacent objects were presented with the following patterns of movement: either the two objects moved back and forth together, or the little object slid back and forth against the other object, which stood behind it without moving. In either case, the objects remained adjacent throughout the movement. Not surprisingly, the infants reached for the two objects as a whole when they moved together. When the little object moved independently, however, infants reached for it directly.

Did infants reach for the little object when it moved independently because they perceived its boundaries for the first time, or did they reach for it simply because they are attracted to surfaces that move? The next study addressed this question by presenting the adjacent objects under conditions in which the little object was always stationary. In one condition, the larger object was stationary as well; in the other condition, the larger object was presented in motion. Infants reached for the two objects as a whole when the objects were both stationary. In contrast, they reached primarily for the little object when that object was stationary and the larger object moved behind it. Thus, the infants were not attracted by motion per se--they did not simply reach for any surface that moved. Rather, infants reached for the boundaries of the objects, as those boundaries were specified by the patterns of relative movement. When one object moved independently of the other, infants appeared to

perceive them as distinct things that were separately manipulable.

Further experiments investigated how movement affected perception of the objects that were separated in depth. Two such objects evidently are perceived as distinct when they are stationary. The introduction of certain patterns of movement, however, might be expected to change that perception. If infants have the notion that each object in a scene will move independently of the other objects around it as long as it does not bump into anything, then infants should perceive two objects that are separated in depth as a single connected unit when the objects move together. Accordingly, the separated objects were presented to infants under conditions in which the objects moved together, in which only the little object moved, or in which only the larger object moved. Once again, infants reached for the little object both when it moved independently, and when the larger object moved independently behind it. When the objects moved together, however, infants' reaching showed a striking change: They reached for the configuration of two objects as a whole. The common movement of these objects may have led infants to infer that the objects were connected, even though no connection between them could be seen.

In summary, the findings of studies using adjacent objects and objects separated in depth are fully consistent with the findings of the studies of partly occluded objects. In all these studies, infants appeared to perceive objects by analyzing the spatial arrangements and the movements of surfaces, and not by analyzing the gestalt properties of surfaces. The findings of these experiments suggest that infants conceive of the world as composed of things that are spatially connected, separately moveable, and moveable only as wholes. What is more, infants take these things to be countable and graspable. A good part of our adult conception of objects seems to be present in infancy.

7. Conceiving of the solidity and persistence of objects

Still, it is possible that the infant's conception of an object differs from our own in some further, important respects. First, we as adults conceive of objects as moveable, but only in certain ways. Objects must move continuously through space and time; they cannot jump from one place to another. Second, we conceive of objects as occupying space and constraining each others' movements: one object cannot pass through a region that is

occupied by another object. Third, we conceive of objects as persisting over their movements, even when their movements carry them from view. Objects do not seem to go out of existence when they leave our sight.

An early experiment by Bower (1967) suggested that young infants also have the notion that objects persist when they move out of view. Bower conditioned infants to suck on a nipple for a reward in the presence of an object--a disk--and only in the presence of that object. He found that the infants continued sucking when the object was gradually occluded--a finding that suggested that the infants knew that the object continued to be present, even though it was not visible.

Despite this finding, other observations by Piaget (1937/1954), Bower (1982), and many others seem to show that infants' conceptions of objects differ markedly from our own. These observations focus on infants' search for objects. In brief, young infants are often terribly inept at finding objects that are hidden. They may fail to do anything to retrieve an object that moves from view: young infants will not knock over a barrier, remove a cover, open a box, or even turn to look at a place where the object might be expected to reappear. These failures are not brought about by superficial problems of motor control: Infants will fail to search for an object under a cover, for example, long after they are capable of lifting covers. When infants do begin to retrieve hidden objects at about 8 months, moreover, they often make bizarre errors, searching in places where an object could not possibly be. For example, an infant who has just seen an object being placed under a cover to his left will sometimes search for the object under a cover to his right. These search errors have led most investigators to propose that infants' conceptions of objects are quite different from our conceptions as adults. Following Piaget (1937/1954), many contemporary psychologists have concluded that young infants think objects come into existence and go out of existence "capriciously," jumping from place to place and from time to time as they enter and leave the field of view. It is possible, however, that infants' errors in searching for objects stem from conceptual difficulties posed by the search task itself and not from any bizarre conceptions of objects.

An experiment has been conducted to test this possibility, and to investigate infants' conceptions of the persistence of objects in a new way. This experiment (Baillargeon and Spelke, 1983) attempts to assess infants' knowledge about objects in a situation in which infants do not have to search for anything. We ask whether infants can make an inference about the possible movements of an object when that inference depends on all three of the conceptions outlined above: the notion that objects move continuously, the notion that objects cannot pass through other objects, and the notion that objects continue to exist when they move freely out of sight.

The critical events in this study are depicted schematically on Figure 9. A block and a screen were presented on the floor of a wooden display box that was open only on the side that faced the infants. The screen lay flat on the floor of the box, a short distance in front of the block. While the infants observed this display, the screen rotated upward about its far edge. After it had rotated about 70 degrees, it had completely occluded the block behind it. The screen then continued rotating, and either of two events occurred. In one event, the screen rotated about 120 degrees, until it reached the place where the block had stood. At that point, it stopped and reversed direction, returning to the table and revealing the block again. In the other event, the screen rotated for a full 180 degrees, through the place that the block had occupied, until it was lying flat on the table in the position where the block had been. Only then did it reverse direction, eventually revealing the block. (These events were actually created by means of two separate display boxes, whose images were reflected to the same position, at different times, by mirrors.) To adults, the first of these events is possible, but the second is not. We can see that the block could not have moved from its original location: Since no object can pass through a solid wall like the back wall of the display box, and since no object can jump discontinuously from one place to another, the block could not have moved out of the path of the occluding screen without being seen. Thus, the screen appears to have moved freely through the place that the block currently occupied, and this, we adults know, cannot happen.

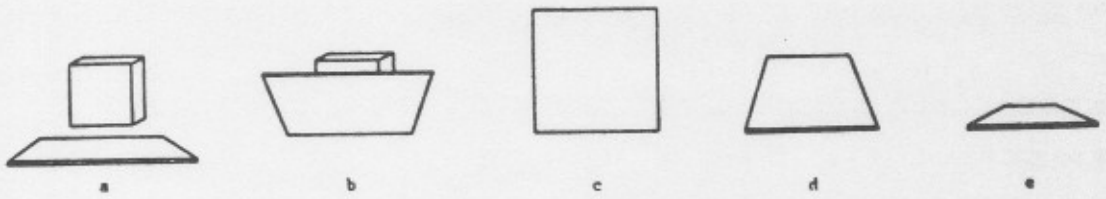


Figure 9. The events end at d (possible) or e (impossible).

To learn how infants conceive these events, we conducted an experiment much like the earlier studies. Five-month-old infants were first familiarized with an event involving only the screen. On each of a series of trials, they saw the screen rotate on the empty table through the full 180 degrees, repeatedly. Then the block was introduced, and infants viewed the 120 degree and the 180 degree rotations in alternation. If infants do not conceive of objects as existing behind their occluders, or if they do not know that objects can only move continuously through unoccupied space--that objects cannot pass through one another or jump, discontinuously, from the inside to the outside of the box--then the infants should show little interest in the new 180 degree rotation. This is, of course, the very rotation with which they have been presented all along. In contrast, if infants conceive of objects as we do, then they should show renewed interest in the 180 degree rotation. For although this event is superficially quite similar to the original, familiar event, it is deeply different. For the first time, the screen does not move through empty space, but through space occupied by an occluded object, in violation of principles of physics that we accept as adults.

The results were straightforward: the infants looked markedly longer at the 180 degree rotation than at the 120 degree rotation. They were more interested in the event that was superficially the same as the original event, but in which the screen passed through space occupied by the occluded block. The experiment provides evidence that young infants can and do know about the existence and the possible movements of fully occluded objects. They know that an object persists in a definite place over occlusion, that it cannot jump out of a box that fully encloses it but rather must move on continuous paths, and that its presence constrains the possible movements of other objects. Difficulties in searching for objects still need to be explained--perhaps in terms of the development of memory or the development of

abilities to coordinate separate actions together. But young infants appear to conceive of objects much as we do as adults.

8. Infants' conceptions of objects

The findings of all these experiments suggest that infants conceive of the world as composed of spatially connected and separately moveable units. These units must move continuously through space and time, and they can move only through places not occupied by other things. Moreover, these units tend to persist when they move freely, maintaining their internal coherence and their external boundaries. Infants' conceptions of objects seem to underlie their organization of visual scenes into units, their attempts to count and to manipulate things in the scene, and their predictions about the outcomes of events in which objects move.

To be sure, infants do not appear to conceive of objects in all the ways that we do as adults. It seems very likely that they lack most of our conceptions about objects of particular kinds. Our experiments provide evidence, moreover, that infants do not know that objects tend to be uniform in their substances and regular in their shapes. Finally, infants probably lack many of our general conceptions about the behavior of material bodies. They probably do not know that all objects will melt at sufficiently high temperatures, and they may not know that objects will tend to move on certain kinds of trajectories. Research by Keil (1979) suggests that young infants do not know that most material objects will fall to the ground if they are not supported. Nevertheless, infants seem to have some conceptions of objects that we retain throughout life.

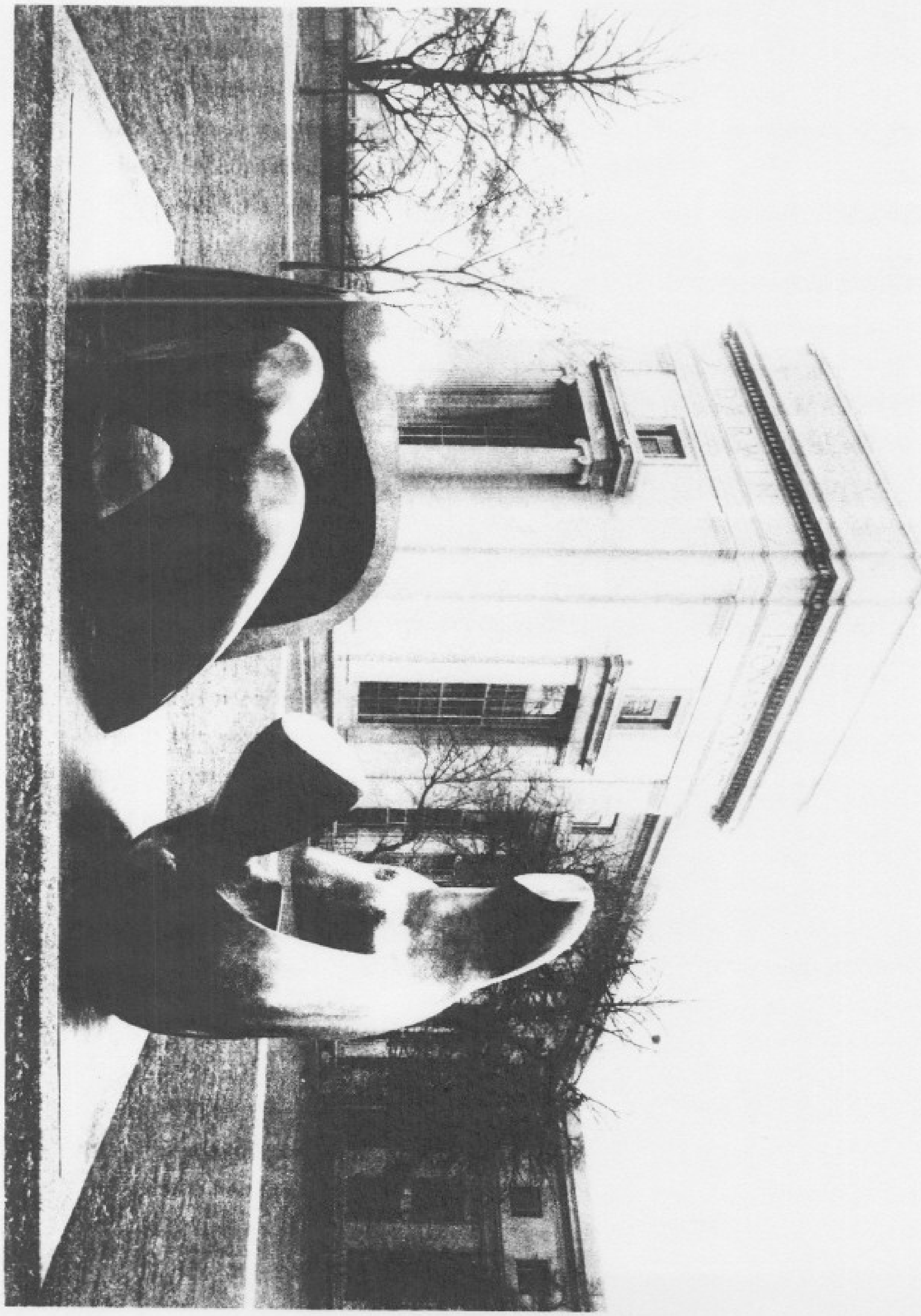
These experiments are hard to explain on the traditional view that infants respond to sensations of light, color, and perhaps motion, but are unable to structure these sensations into a world of external, independent objects. For example, when infants are presented with two objects of the same color that are adjacent or are separated in depth, the traditional view leads to the prediction that the two objects will be perceived as a single region of the visual field. We have found, in contrast, that infants perceive two adjacent objects as one unit and two objects that are separated in depth as two units. Similarly, the traditional view dictates that infants respond only to the visible surfaces of things, not to the configuration of objects

that gives rise to a visual pattern. We have found no evidence, however, that infants are even able to respond to visible surfaces per se. Infants did not treat two rods with a gap between them as similar to a partly hidden rod, even though the visible rod parts were the same in these two displays. Infants also did not perceive two identical rotations of a screen as similar, when one rotation carried the screen through empty space and the other carried it through a hidden object. In short, infants do not seem to be captives of sensation, of the here-and-now. They appear to apprehend a world of enduring physical objects.

9. Mature conceptions of objects

How do infants' conceptions of objects relate to our conceptions of objects as adults? Let me suggest that the infant's conceptions of objects are the central conceptions we adults hold. These conceptions are more powerful, more widely appealed to, and more resistant to change than either our specific notions of objects of particular kinds or our general notion that objects tend to be regular in shape and uniform in substance. As evidence, consider the kinds of things that adults will think of as objects. Prototypical objects are probably not only coherent and moveable, but also simply shaped, uniformly colored, and belonging to known kinds with characteristic properties and functions. But we would consider an unknown, irregularly shaped, complexly colored body of matter as an object as well, if it is internally coherent and separately moveable. These bodies are things we will readily count, name, act on, and learn about. We are much less apt to consider something an object if it is not coherent: a pile of rocks, for example, or a mound of sand.

Some of our intuitions about identity point, I think, in the same direction. In prototypical cases, adults think of objects as maintaining not only their coherence and separate moveability but also their characteristic shapes, substances, and other properties through time. But we consider most objects to persist over quite substantial changes in shape, substance, and function. We are much less likely to consider an object as persisting over a change that destroys its coherence or its boundaries. Adults also resist considering something to be a single, persisting object if it moves discontinuously, jumping from one place to another. When we see an object at two different times, in circumstances in which no single object could have moved continuously from the first place to the second, we usually conclude that we have seen two distinct things. Indeed, in the cases in which we do take two



speaker points to a pile of china fragments and says "look at poor grandmother's cup," we are happy to consider the fragments as an object. And some things we consider objects are never connected and coherent: a book in several volumes, for example, or a Henry Moore reclining figure made of three pieces of bronze (Figure 10; see also Cartwright, 1975; Chomsky, 1975).

I suggest, however, that our general conception guides us even in these cases, in a special way. We do not always think of separated pipe pieces, china fragments, or lumps of bronze as one object. As many people have pointed out, we think this way only when we see each of these collections as an object of a certain sort: a pipe, a cup, or a sculpted figure (e.g., Geach, 1962; Wiggins, 1980). It is less often noted, however, that these sortal concepts apply to objects that are usually spatially connected and separately moveable. Sortal concepts may lead us to confer unity on collections of distinct bodies because they lead us to view those collections as parts of something that would normally be spatially connected. We may think of a broken cup as an object, for example, because we see it as a deviant instance of something that is normally one body. The same may be true of two-volume books and three-piece sculptures, although these examples may introduce further complications, insofar as we do not straightforwardly think of a work of art or literature as a material object. Sortal concepts play a role in singling out objects, I suggest, because they cover pieces of the world that are standardly connected, separately moveable, and persisting.

It is striking that our sortal terms tend so strongly to apply to spatially connected, coherent, and continuously moveable things. We often lack single words for collections of spatially distinct objects even when it would be useful to have them. Thus, there is no singular term for a nut and a bolt, a cup and its saucer, a car and its ignition key, or a pair of chopsticks or knitting needles. We also lack ordinary sortal terms for entities that jump in space or time. Physicists may conceive of particles that move discontinuously, and science fiction writers may describe spaceships with this power, but such things do not seem to be found in our ordinary thinking and language, and we do not appear to embrace them easily. Why might this be? Because, perhaps, we conceive of objects as spatially connected and separately, continuously moveable. This conception may have guided the development of all our sortal concepts, causing us to embrace only concepts of certain kinds. If this view is correct, then our initial conception should continue to stand at the center of our thinking

about the physical world, for it perpetuates itself in all the further conceptions we gain.

I am suggesting, then, that adults have a core conception of objects, and it is the very conception with which infants are born. Development brings us new conceptions, some of them quite general, but these new conceptions do not displace the core conception. New conceptions of objects grow on the periphery of a set of notions that are innate, that are present throughout life, and that do not change.

10. Afterword

The development of children's knowledge is not usually conceived as a process of continuous growth around a core of unchanging conceptions. Nevertheless, this pattern of development may characterize not only the growth of conceptions of objects, but the growth of conceptions of many kinds. For example, the child's conceptions of number, of space, of music, and of the actions and mental states of other people may all develop around a constant core of notions. It is reasonable to suppose that core conceptions exist in any domain in which knowledge develops quickly and spontaneously. In order to learn spontaneously about objects, or events, or states of affairs, infants must be able to interpret their experience in the right ways, singling out those objects and events and states as things to learn about. This task may be solved in many cases by bringing to bear an initial conception of the world and of the things of which it is composed (see Chomsky, 1980; Fodor, 1975, 1983). Such initial conceptions, where they exist, are virtually bound to perpetuate themselves. For example, children who conceive of objects as unitary and separately moveable will be led naturally to perceive particular objects by analyzing the spatial arrangements and the movements of surfaces. Thus, unitary, moveable things will be what these children perceive, and what they are in a position to learn about. These are the things children will develop categories for, the things children will trace through time and learn the histories of, the things children will count and communicate about. In this way, our original conceptions will tend to perpetuate themselves in all that we learn.

If this account is correct, then studies of cognition in infancy can shed light in a special way on our conceptions as adults. They may help reveal what our deepest and most universal conceptions are--the conceptions that we hold most strongly, that we share with all other people, and that we may be bound to hold, whatever our experience, as long as the world permits us to develop any conceptions at all. These conceptions can be discerned, I believe, in the thoughts and the actions of human adults. They are overlaid and partly masked, however, by the diverse, more specialized notions that we have acquired. The conceptions of human infants are more nearly free of these embellishments. In infants, therefore, some of our central conceptions may be seen more clearly.

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