13

PREFERENTIAL-LOOKING METHODS AS TOOLS FOR THE STUDY OF COGNITION IN INFANCY

Elizabeth S. Spelke

University of Pennsylvania, Philadelphia

Introduction 323
Looking at Novel Displays: An Index of Knowledge of Visible Objects 325
Perception of Partly Hidden Objects 326
Perception of the Boundaries of Adjacent and Separated Objects 333
Perception of Configurations of Elements in Visual Patterns 336
Perception and Knowledge of Objects of Particular Kinds 338
Some Limitations of the Methods 339
Looking at Sounding Objects: An Index of Knowledge of Intermodal Unity 343
Perception of Auditory-Visual Relationships 344
Knowledge of the Properties of Sounding Objects 346
Knowledge of Number 348
Selective Visual Attention 349
Some Limitations of the Methods 349
Looking at Novel Events: An Index of Knowledge of Physical Causality 354
Knowledge of the Causes of Object Movement 355
Knowledge of the Persistence of Material Bodies 356
Limitations of these Methods 358
Conclusion 358
References 361

INTRODUCTION

This chapter has two themes. One is a substantive thesis: Human infants are endowed, by nature, not only with capacities to sense elementary properties of light and other stimulation, but with capacities to perceive and to conceptualize the world. Infants have perceptual and cognitive capacities that allow them to apprehend objects and to make sense of certain events. The second theme is methodological: The cognitive capacities of infants can be studied experimentally. In particular, these capacities may reveal themselves over the course of simple experiments in which two or more displays are presented to an infant and looking time to each display is recorded. Studies that use *preferential-looking methods* provide an especially valuable research tool for the study of perception and cognition in infancy.

Why focus on preferential-looking methods? One reason is practical. Stable and reliable behavioral preferences are manifest in the young of many species. Immature animals will often choose systematically to approach, to follow, or to contact one display rather than another (Gottlieb, this volume). Human infants are no exception. They systematically direct their actions toward certain kinds of displays when they reach (Yonas & Granrud, this volume) and crawl (e.g., Gibson & Walk, 1960; see Gibson & Spelke, 1983, for a review) as well as when they look. Looking preferences may be especially useful for research with human infants because these preferences emerge so early relative to other behavioral systems. To be sure, the capacity for visual exploration does not appear full-blown at birth: young infants see very poorly compared to adults (Teller, this volume), and they move their eyes and heads in a far less skilled manner (Aslin, this volume). Nevertheless, the visual behaviors of infants appear to be more advanced than any of their other directed actions. At 4 months, infants cannot yet locomote independently, and they cannot reach for and apprehend objects. Nevertheless, infants of this age and even younger ages show systematic patterns of looking under different stimulus conditions. These patterns serve to mark the events that infants detect.

The second reason for focusing on preferential-looking methods is more important. In infancy, active looking appears to be a kind of exploratory behavior. Like all exploratory behavior, it is guided by what infants already sense and know, and it is directed toward that which they seek to understand. If infants have initial conceptions of objects and events and initial abilities to enrich those conceptions through learning, then these conceptions and abilities should affect infants' patterns of visual exploration. Thus, observations of preferential looking may help to reveal both the notions with which infants begin and the problems they first attempt to solve.

This chapter will focus on two patterns of visual preference. First, infants are apt to look at an object or event that is relatively novel or surprising, in preference to an object or event that is familiar or expected. This preference appears to reflect a general tendency to explore at times and in places where there is new information to be gained. The decline of interest in a familiar event, and the renewed interest in novel events, are usually referred to as "habituation" and "dishabituation," respectively, although it is not clear whether the preference to look at a novel display is truly akin to other forms of habituation (see Tighe & Leaton, 1976; Bornstein, this volume). Second, infants are apt to look at an object or event that is accompanied by a related sound, in preference to an object or event that is accompanied by an unrelated sound. This preference may reflect a general tendency to explore one object or event at a time. Infants, like adults, may avoid attempts to follow two unrelated episodes—one visible and one audible—simultaneously.

Since the pioneering studies of Fantz (1961; see also Fantz, Fagan, & Miranda, 1975), there has developed a large body of experiments that use preferential-looking methods to investigate infants' perceptual and cognitive capacities. These experiments are too diverse to be encompassed easily in one chapter. Accordingly, this chapter will be concerned only with experiments that investigate (a) what infants know about the unity and boundaries of objects in visual scenes, (b) what infants know about relationships between visible objects and their corresponding sounds, and (c) what infants know about the persistence and the behavior of objects that move from view. The results of these experiments suggest, I believe, that patterns of preferential looking reflect more than an infant's capacity to detect color and pattern, and even more than an infant's capacity to perceive depth and motion. Looking preferences seem to reflect infants' initial perceptions and conceptions of objects and events. If this suggestion is correct, then preferential-looking methods can be used to address, through experiments, long-standing questions about the origins and the development of human knowledge.

LOOKING AT NOVEL DISPLAYS: AN INDEX OF KNOWLEDGE OF VISIBLE OBJECTS

The experiments described in this section focus on the ability to perceive visible objects as unitary and bounded. Human adults perceive the boundaries and the complete shapes of objects with an ease that is remarkable, for those boundaries are not reflected, in any simple way, in the pattern of light at the eye. The objects that we see are almost always adjacent to other objects: Objects that are fully suspended, like soap-bubbles, are rare. Adults, nevertheless, perceive each object as distinct from the things that touch it. The objects we see, moreover, are always partly hidden from view: every opaque object has a back that is hidden, and most objects have forward surfaces that are partly obscured by nearer objects as well. Adults perceive each object as complete, despite these patterns of occlusion.

The ability of adults to perceive visible objects appears to depend, in part, on conceptions about objects, their properties, and their behavior (see Spelke, 1983). For example, we appear to conceive of the world as composed of things that are relatively uniform in their shapes, colors, and textures, and this conception may lead us to group surfaces into simple, regular units in the ways that the gestalt psychologists described. We expect that these things can move and that they will move as wholes, separately from each other, in certain trajectories. This expectation may lead us to perceive objects by detecting patterns of motion. Finally, we conceive of the objects around us as instances of certain kinds, like cups and carrots, with characteristic properties and patterns of behavior. Once we can recognize what kind of thing a particular object is, our knowledge about things of its kind allows us to apprehend aspects of the object that would otherwise be obscure.

At least since the work of Piaget (1954), students of infant cognition have explored the origins and the development of conceptions of objects by focusing on infants' ability to perceive objects in visual scenes. Experiments have investigated whether, and under what conditions, infants perceive the unity of an object that is partly hidden and the boundaries of two objects that are adjacent or separated. By assessing the conditions under which infants perceive objects, such experiments promise to shed light on the origins and the development of underlying conceptions of objects.

Perception of Partly Hidden Objects

The first studies of perception of partly hidden objects, by Piaget (1954), used reaching and other manual activities as measures. These studies suggested that infants below about 7 months do not perceive the complete shapes of objects that are partly hidden. For example, Piaget's three children were able to reach for an attractive toy when it was fully in view by the age of about 4 months, but they failed to reach for the same toy when it protruded from under a cloth that partly occluded it until they were 6 to 8 months old. It appeared that the infants did not perceive the toy as complete when it was partly hidden. As a second example, one of Piaget's children readily reached for his bottle when the nipple of the bottle was oriented in his direction, but until 9 months of age, he failed to reach for the same bottle when it was rotated so that the nipple was out of view. The infant did not appear to perceive this object as having a back, or to recognize the object when it was rotated so that its visible and invisible sides were interchanged.

It is possible, however, that failures to manipulate objects appropriately derive from the infant's immature capacities to coordinate actions (see Piaget, 1952), and not from any inability to perceive and recognize objects. Infants might recognize a toy, for example, and yet fail to reach for it when it is partly covered, because they do not know how to extricate it from its cover. Infants also might recognize a rotated bottle as a bottle, and yet fail to discern how to rotate it themselves in order to get its nipple to their mouths. It is of interest, therefore, to investigate infants' perception of partly hidden objects by using preferential-looking methods.

A variety of experiments have used a familiarization/novelty-preference procedure. In these studies, 4-month-old infants were presented with a three-dimensional object whose top and bottom were visible but whose center was hidden behind a second object (Figure 1a). The object might be stationary or moving, as in this figure. This display was shown during a series of trials; each trial lasted as long as the baby looked at the object, ending when the baby looked away for 2 seconds. Infants tended to look at this display for 10 to 30 seconds on the first several trials, and then their looking times declined: Attention to the display "habituated." When looking time had decreased to half its original level, the block was removed, and infants were presented with two displays in alternation on six further trials (Figure 1b). One of these displays consisted of the two visible surfaces of the formerly occluded object, separated by a gap where the occluder had been. The other display consisted of a single connected object, created by joining together the two visible ends of the

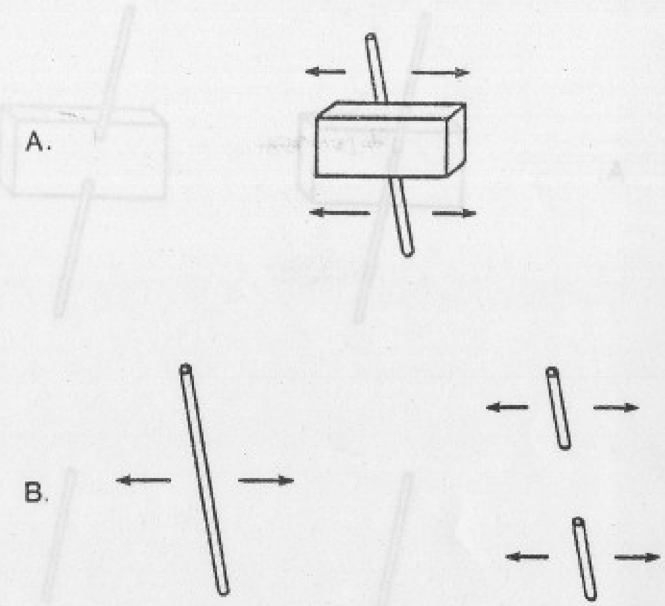


Figure 1. Schematic depiction of (*a*) the habituation display and (*b*) the test displays of an experiment on perception of partly occluded objects. Arrows indicate the path of motion (Kellman & Spelke, 1983).

original object. If infants perceived the visible surfaces of this partly hidden object as distinct and separate, then habituation would be expected to generalize to the display with the gap, and infants should look longer at the connected object. If infants perceived the two visible surfaces as connected behind the occluder—as parts of a single object—then habituation would be expected to generalize to the complete rod display, and the reverse preference should be observed.

Before turning to experiments that use this procedure, it is important to note that the procedure depends on certain assumptions. First, infants who are presented with a partly hidden object must attend to that object, and not only to the object in front of it. Second, the test displays of complete and broken objects must be discriminable and of roughly equal intrinsic attractiveness to the infants. Third, habituation to a configuration of two objects must generalize, to some extent, to one of those objects presented alone, and dishabituation must occur if a new object is presented. Two preliminary experiments were conducted as a check on these assumptions.

In the first experiment (Kellman & Spelke, 1983), infants were familiarized with a stationary solid black rod figure in front of the block that was to serve as the occluding object in the principal studies. Half the infants saw the complete rod and half saw the two separate rod pieces (Figure 2a). After the criterion of habituation was met, infants were shown test displays in which the rod figures appeared without the block (Figure 2b). The results indicated that

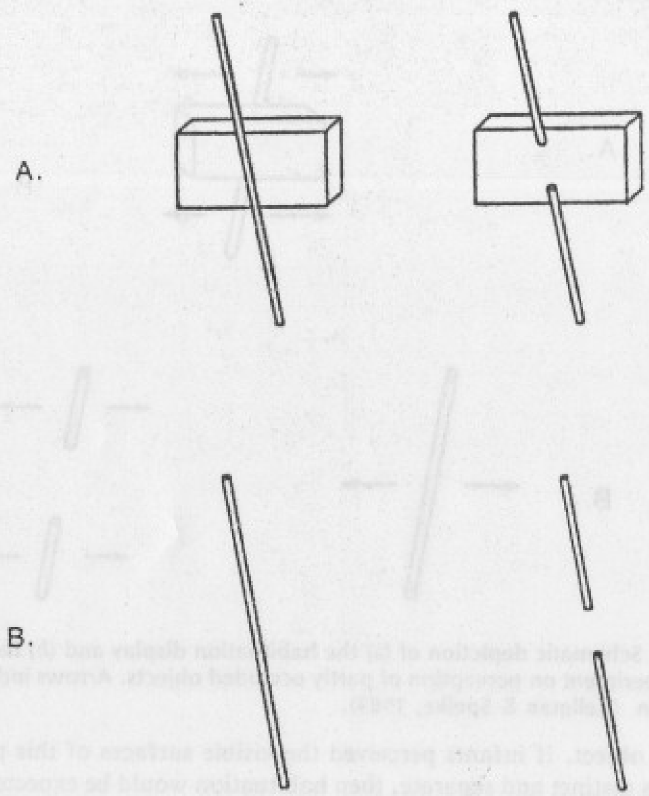


Figure 2. Schematic depiction of (*a*) the habituation displays and (*b*) the test displays of an experiment on habituation to configurations of objects (Kellman & Spelke, 1983).

the infants generalized habituation to the familiar rod figure when it was presented alone, and they dishabituated to the rod figure they had not previously seen. Averaging across the two experimental conditions, infants looked about equally at the two test displays. We may conclude that these complete and broken objects were discriminable and of about equal interest, and that habituation to these configurations of objects generalized to one of the objects presented alone and not to a new object. The habituation method can be used to investigate perception of each object in a configuration of several objects.

The second preliminary experiment (Kellman & Spelke, 1983) assessed infants' responses to changes in the visible surfaces of a partly hidden object, in order to determine whether infants perceive and attend to objects that are partly occluded. Infants in one condition were presented with a rod whose center was hidden by a block: the complete rod and block used in the former study. Infants in a second condition were presented with two rod pieces behind the same occluder, separated by a large visible gap (Figure 3a). After habituation, infants were presented, on alternating trials, with the complete test rod and with two small rod pieces separated by a large gap (Figure 3b). Thus, each

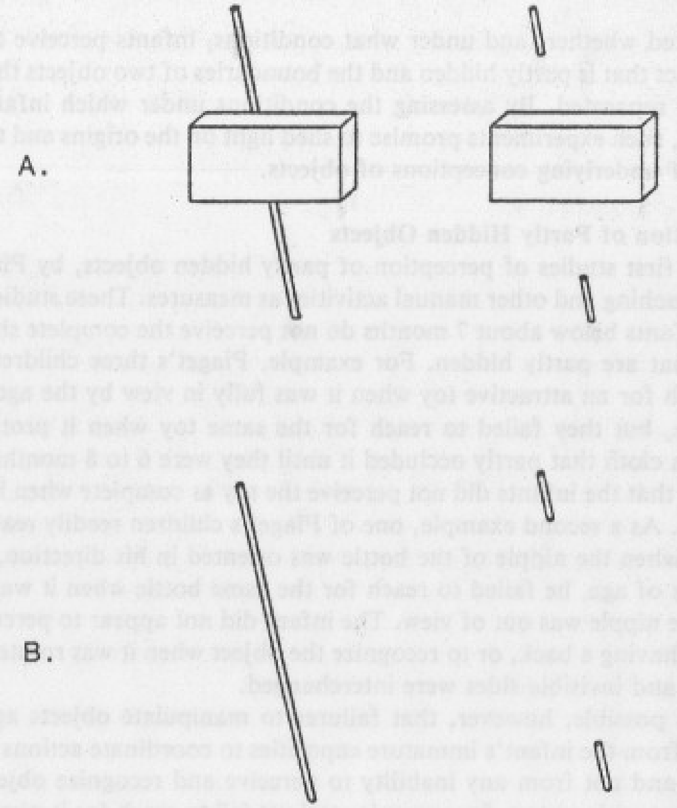


Figure 3. Schematic depiction of (*a*) the habituation displays and (*b*) the test displays of an experiment on perception of the visible surfaces of a partly occluded object (Kellman & Spelke, 1983).

test display matched the visible areas of only one of the original rod figures. Infants looked longer at the test figure that could *not* have been the figure presented during the habituation series. The experiment indicates that infants who are presented with a partly hidden rod figure attend sufficiently to its visible areas to discriminate the figure from a display that differs from it with respect to those visible areas.

Given the findings of these experiments, we may conclude that the familiarization/novelty-preference method provides a feasible means to investigate infants' perception of partly hidden objects. Therefore, a series of experiments was undertaken. In one experiment (Kellman & Spelke, 1983), infants of 4 months were presented with the black rod moving back and forth behind the occluding block, as in Figure 1, such that its center never came into view. Adults perceive the ends of this rod as connected behind the block, since the ends move together and can be joined to form an object with a homogeneous color and a regular shape. After habituating to this display, infants were presented on alternating trials with the complete rod and with the two rod pieces separated by the small gap where the block had been, moving in the same manner. In a separate experiment, infants of this age were found to look equally at these test displays when the displays were equally familiar. Nevertheless, the infants in the principal experiment looked longer at the rod with the gap. The experiment provides evidence that the infants perceived the ends of the original rod to be connected behind the block: They perceived the complete shape of this partly hidden object.

Subsequent experiments indicated that infants perceive partly hidden objects by analyzing the movements of surfaces but not by analyzing the colors and forms of surfaces. In different studies (Kellman & Spelke, 1983; Schmidt & Spelke, 1984; Termine, Hrynick, Gleitman, & Spelke, in preparation), infants have been presented with a single rod, a triangle made of rods, a solid sphere, a solid cube, and a large flat surface (Figure 4). Each object appeared without moving, behind a block that occluded its center. In all cases, habituation to these displays was followed by equal looking at complete and broken test displays. This equal looking could not have stemmed from a failure to attend to stationary objects that are partly hidden, since infants did attend to the stationary rods in the preliminary experiments. The equal looking also was not a statistical artifact of averaging together two distinct subgroups of infants, each of which dishabituated to one of the two test displays. Inspection and analysis of the distributions of looking times in the different experimental conditions revealed that the looking scores were unimodally distributed, with similar variances across conditions. It appears, therefore, that infants have no determinate perception of the complete shape of a partly hidden, stationary object.

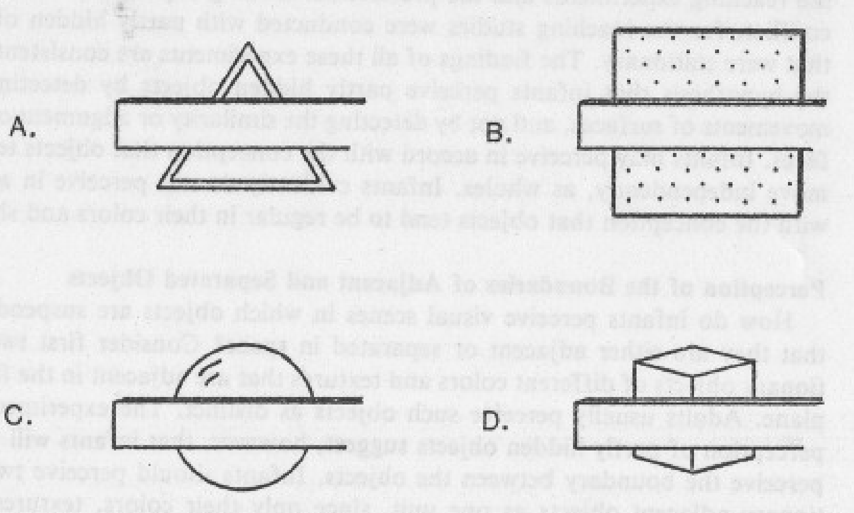


Figure 4. Schematic depiction of the occlusion displays of experiments on perception of partly hidden objects (Kellman & Spelke, 1983, display *a*; Termine, Hrynick, Gleitman, & Spelke, in preparation, display *b*; Schmidt & Spelke, 1984, displays *c* and *d*).

In a further study (Kellman & Spelke, 1983), infants were presented with a moving object with a very irregular shape. The object was composed of two surfaces of different colors and textures, with misaligned edges (Figure 5). When these surfaces moved together in a common translation behind an occluding block, infants perceived the surfaces as connected. After they became familiar with this display, they showed as strong a preference for the broken display as did infants in the original moving rod experiment. All these experiments provide evidence that infants perceive objects by detecting the movements of surfaces. Surfaces that move together rigidly are perceived to be connected in the places where they are hidden. The experiments also provide evidence that infants do not perceive the complete shapes of partly hidden objects by organizing visual displays into units of maximally regular shapes and colors. Infants appear to perceive the complete shapes of partly hidden objects under some, but not all, the conditions that are effective for adults.

In brief, 4-month-old infants' patterns of looking at displays of objects, presented successively, seem to reflect their perception of the objects and their boundaries. If infants perceive a partly hidden object as a complete object with a certain shape, habituation to the object together with its occluder will generalize to the object presented alone and fully in view. Note that this looking pattern need not have been observed, even granting that infants can perceive the complete shapes of partly hidden objects. Infants might have habituated and dishabituated to more superficial aspects of an occlusion display: to prop-

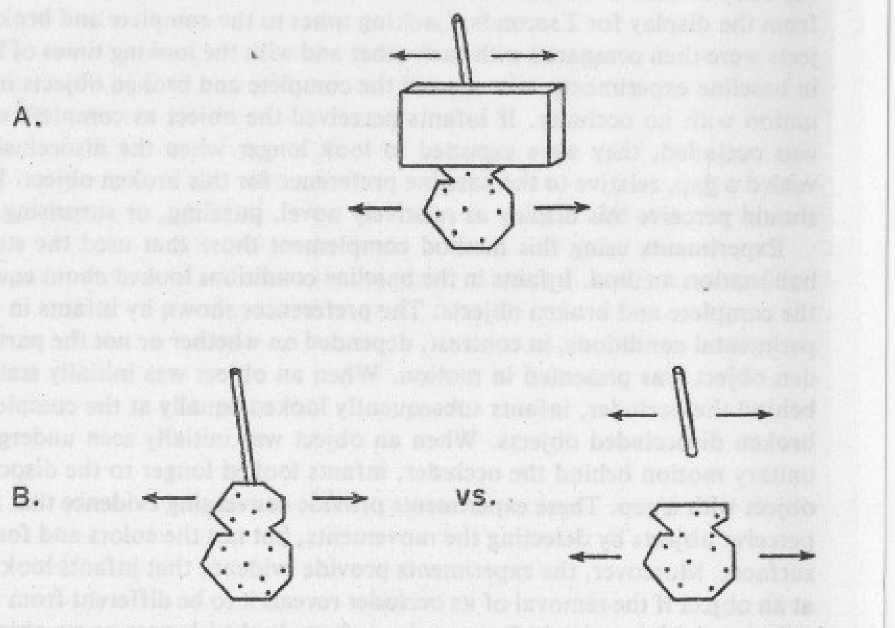


Figure 5. Schematic depiction of (*a*) the habituation display and (*b*) the test displays of an experiment on perception of partly occluded objects. Arrows indicate the path of motion (Kellman & Spelke, 1983).

erties of the visible surfaces of an object rather than to properties of the object itself. For example, infants might have perceived the original display as a unitary rod, but they might also have perceived that only two parts of the rod were visible. When the complete and broken test rods were presented, the former might have appeared more novel, because it contained a new pattern of visible surfaces, even though it contained a familiar object. In no experiment, however, was there a preference for the complete test display. Infants looked equally at the complete and broken test displays after seeing a partly hidden object that was stationary, and they looked longer at the broken display after seeing a partly hidden object in motion. In these experiments, the infants habituated to the perceived objects themselves and not to any patterns of visible surfaces.

Infants' perception of partly hidden objects can be assessed not only through multi-trial habituation procedures, but also through procedures that focus on infants' spontaneous attention to an object that is originally partly occluded and then is disoccluded. In a series of experiments (Schmidt & Spelke, 1984), 4-month-old infants were presented with a partly occluded, moving or stationary object. They were allowed to look at this display for 5 seconds, and then the occluder was moved to the side, revealing fully the object that had stood behind it (Figure 6). On half the trials, the disocclusion revealed a complete object; on the other trials, it revealed an object with a formerly hidden gap. Every time an object was disoccluded, it remained present for as long as the baby looked at it, and was removed only when the baby had looked away from the display for 2 seconds. Looking times to the complete and broken objects were then compared with each other and with the looking times of infants in baseline experiments, who viewed the complete and broken objects in alternation with no occluder. If infants perceived the object as complete while it was occluded, they were expected to look longer when the disocclusion revealed a gap, relative to the baseline preference for this broken object. Infants should perceive this display as relatively novel, puzzling, or surprising.

Experiments using this method complement those that used the standard habituation method. Infants in the baseline conditions looked about equally at the complete and broken objects. The preferences shown by infants in the experimental conditions, in contrast, depended on whether or not the partly hidden object was presented in motion. When an object was initially stationary behind the occluder, infants subsequently looked equally at the complete and broken disoccluded objects. When an object was initially seen undergoing a unitary motion behind the occluder, infants looked longer to the disoccluded object with a gap. These experiments provide converging evidence that infants perceive objects by detecting the movements, but not the colors and forms, of surfaces. Moreover, the experiments provide evidence that infants look longer at an object if the removal of its occluder reveals it to be different from the object they had perceived. Once again, infants looked longer at an object that was novel and perhaps unexpected, even though its visible surfaces matched the visible surfaces of the object in the original occlusion display.

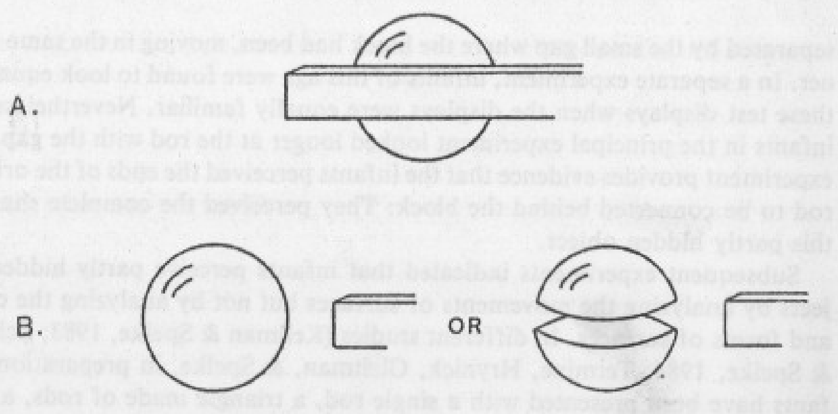


Figure 6. Schematic depiction of (a) the occlusion display and (b) the disoccluded objects of an experiment on perception of partly occluded objects (Schmidt & Spelke, 1984).

How do the findings of experiments using preferential-looking methods compare to those of the experiments using reaching methods? In one respect, these experiments support opposite conclusions. Recall that Piaget, drawing on observations of infants' reaching, concluded that young infants perceive only the visible surfaces of objects, not their complete shapes. The preferential-looking experiments, in contrast, suggest that infants never perceive just the visible surfaces of things. Depending on the stimulus conditions, infants either have no determinate perception of a partly hidden object, or they perceive the object as continuing where it is hidden. Nevertheless, the findings of the reaching experiments and the preferential-looking experiments are not in conflict, for the reaching studies were conducted with partly hidden objects that were stationary. The findings of all these experiments are consistent with the hypothesis that infants perceive partly hidden objects by detecting the movements of surfaces, and not by detecting the similarity or alignment of surfaces. Infants may perceive in accord with the conception that objects tend to move independently, as wholes. Infants evidently do not perceive in accord with the conception that objects tend to be regular in their colors and shapes.

Perception of the Boundaries of Adjacent and Separated Objects

How do infants perceive visual scenes in which objects are suspended so that they are either adjacent or separated in space? Consider first two stationary objects of different colors and textures that are adjacent in the frontal plane. Adults usually perceive such objects as distinct. The experiments on perception of partly hidden objects suggest, however, that infants will fail to perceive the boundary between the objects. Infants should perceive two stationary adjacent objects as one unit, since only their colors, textures, and shapes can serve to separate them.

The first studies of perception of adjacent objects, again, were reaching experiments. Although infants of 5 months and beyond will reach reliably for a small object that is dangled on a string, perched on the tips of an adult's fingers, or allowed to slide across another object, they fail to reach for a small object when it is stationary and rests solidly upon a second object. When 5- and 6-month-old infants are presented with a matchbox resting on a book, for example, they reach primarily for the larger, supporting object (see Bresson & de Schonen, 1976-1977; Piaget, 1954; and Wishart, 1979, for these and related observations). Piaget (1954) suggested that infants perceive two adjacent objects as a single unit when they are stationary, and as two objects when they move independently—just as one would expect if infants perceive objects by analyzing the movements and spatial contiguity of surfaces but not by analyzing the forms and colors of surfaces. It is possible, however, that reaching was unrelated to object perception. Infants might have reached for the matchbox when it moved on the book because they prefer to reach for surfaces that move, and they might have reached for the book when both objects were stationary because they prefer to reach for surfaces that are nearby. Experiments indicate that infants have such reaching preferences (e.g., Yonas, this volume). Thus, it is important to investigate infants' perception of adjacent and separated objects through observations of activities unrelated to reaching. Once again, preferential-looking methods can serve this purpose, as is illustrated by the next experiment.

In this experiment (Kestenbaum, Termine, & Spelke, in preparation), 3-month-old infants were familiarized with a display of two objects that were either adjacent or spatially separated. The displays were constructed so that the objects in one display were of the same size and distance from the baby as the objects in the other display. To accomplish this, the objects were arranged so that they were either adjacent or separated *in depth:* One object was presented in front of the other, so that they were or were not touching (Figure 7). In both displays, the objects overlapped fully at the infant's eye, however far a baby moved his or her head. Very slight head movements, however, allowed adults (and, presumably, infants) to see that the separated objects were discontinuous in depth (the sides of the nearer object ended well before the front of the further object), and that the adjacent objects were contiguous in depth (the sides of the nearer object met the front of the more distant object). After habituation, the infants were shown displays in which either one or both objects appeared in a new position closer to the infant, so that the spatial relationship of the objects was either changed or preserved. When only one of the adjacent objects was displaced, it was moved so that the objects were no longer adjacent. If infants had perceived the two objects in the original display as one unit, they were expected to look longer at the new display, in which only one object appeared in a new position. This display should now be seen as two objects, each quite unlike the object infants had perceived before. In contrast, if infants had perceived the objects in the original display as distinct, then they were expected to look equally at the two novel displays, for neither of these displays would be perceived to contain any objects that were new.

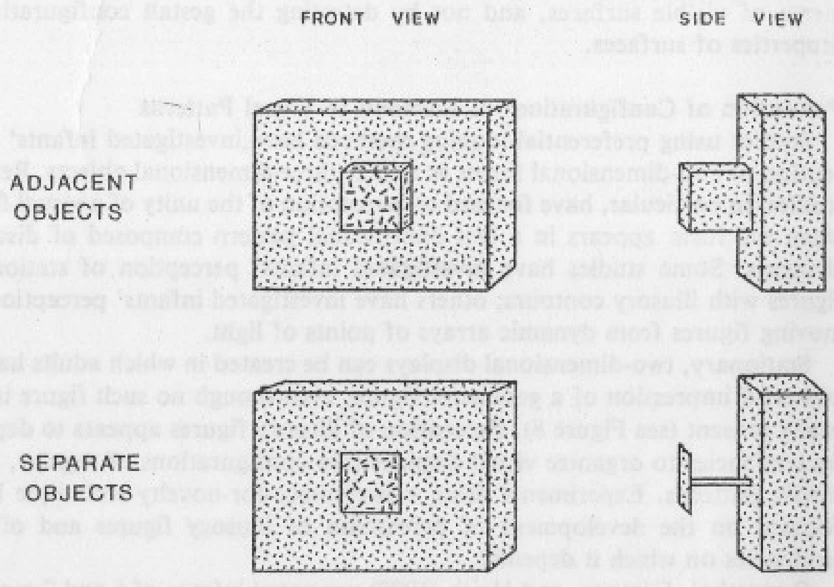


Figure 7. Schematic depiction of the displays of an experiment on perception of adjacent and spatially separated objects (Kestenbaum, Termine, & Spelke, in preparation).

The experiment used the same method as the original studies of perception of partly hidden objects. One group of infants was familiarized with the display of adjacent objects, and a second group was familiarized with the display of separated objects. Then the two test displays were presented on six alternating trials. The results were clear. The infants who had been presented with the objects that were separated in depth subsequently looked equally at the two test displays. In contrast, the infants who had been presented with the objects that were adjacent in depth looked longer at the display in which only one object appeared in a new position, changing the arrangement of the objects. The experiment provides evidence that infants perceive two adjacent objects, but not two separated objects, as one configuration.

This experiment suggests, once again, that patterns of visual preference can provide information about infants' perception of the boundaries of objects. Infants evidently looked less and less at displays in which they perceived the same objects, even if the objects were presented in a new arrangement, and they looked longer at a display in which they perceived a new object. The hypothesis that infants' looking patterns reflect their perception of objects is supported by the concordance of the results of this experiment with the results of the studies of perception of partly occluded objects, and also by the concordance of the present findings with the findings of all the reaching experiments. All these experiments provide evidence that infants perceive the unity and the boundaries of objects by detecting the spatial arrangements and the movements of visible surfaces, and not by detecting the gestalt configurational properties of surfaces.

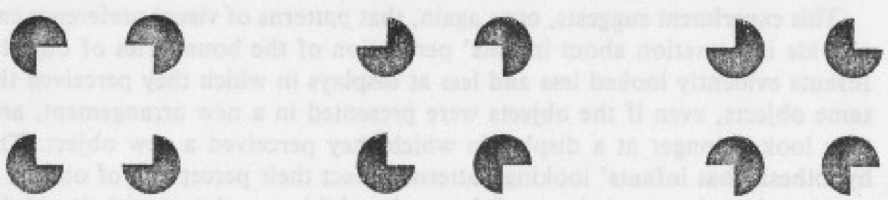
Perception of Configurations of Elements in Visual Patterns

Studies using preferential-looking methods have investigated infants' perception of two-dimensional forms as well as three-dimensional objects. Recent studies, in particular, have focused on perception of the unity of a visual form when the form appears in a two-dimensional pattern composed of discrete elements. Some studies have investigated infants' perception of stationary figures with illusory contours; others have investigated infants' perception of moving figures from dynamic arrays of points of light.

Stationary, two-dimensional displays can be created in which adults have a powerful impression of a geometric figure, even though no such figure is actually present (see Figure 8). Perception of illusory figures appears to depend on tendencies to organize visual displays into configurations of regular, geometric patterns. Experiments using a preference-for-novelty technique have focused on the development of perception of illusory figures and of the tendencies on which it depends.

Bertenthal, Campos, and Haith (1980) presented infants of 5 and 7 months with the displays in Figure 8. These displays all consist of the same elements, but they are perceived quite differently by adults. One is perceived to contain a bright square, whereas the others are not. To investigate how infants perceive these displays, one group of infants was presented repeatedly with the illusory square and then was presented with one of the nonillusory figures. A second group of infants was presented repeatedly with a nonillusory figure, followed by the illusory square. A third group of infants was presented with the two different nonillusory figures.

At 7 months of age, infants were found to look longer at the final test display if the introduction of that display involved a change from an illusory to a nonillusory figure, or the reverse. In contrast, infants did not increase their looking when the displays changed from one nonillusory figure to another. These findings provide evidence that infants are sensitive to the configuration of elements in a display that produces an illusory figure. Infants of 7 months



A. B. C.

Figure 8. Displays used in experiments on perception of illusory figures (Bertenthal, Campos, & Haith, 1980).

do not appear to respond to the individual pattern elements per se: They appear to perceive forms by organizing such elements into figures with maximally regular shapes.

The 5-month-old infants, in contrast, showed little increase in looking at any of the displays and no differential increase in looking when one of the two displays was the illusory figure display. Both in the original experiment, and in a subsequent replication and extension (Bertenthal, Haith, & Campos, 1980, cited in Lamb & Campos, 1982), 5-month-old infants appeared to be insensitive to the configuration of elements in these patterns. It appears, therefore, that infants do not tend to organize two-dimensional visual patterns into units with regular forms.

Adults also perceive unitary, structured forms when they are presented with kinetic, two-dimensional displays in which separate elements—points or circles of light—undergo certain types of movement. Adults perceive a human form when they are presented with a set of lights on the major joints of a walking human body (Johansson, 1978). Furthermore, adults perceive a human face when they are presented with a set of light-reflecting circles, painted on the face, that move and deform as the face moves expressively (Bassili, 1979). Investigators in several laboratories have now presented infants with these moving light displays (Bertenthal & Proffitt, 1982; Fox & McDaniel, 1982; Kaufmann-Hayoz & Jager, 1983; McDaniel & Odom, 1983). Their experiments, which use preferential-looking techniques, have provided evidence that infants are sensitive to the structure in both the walking and the expressive patterns of movement.

One experiment (Kaufmann-Hayoz & Jager, 1983) serves to illustrate the methods and findings. The experiment used a preference-for-novelty method. Infants of 3½ months were familiarized either with spots of light on an animately moving face, or with spots of light on an inanimately moving face mask. Then the infants were presented with the two displays, side by side. In one condition, these displays were presented upright, with the face in its canonical orientation. In the other condition, the displays were presented upside down. The inverted condition is of interest because adults do not easily recognize faces and their expressions at this orientation. The infants showed no consistent preferences between the displays in the upside-down orientation: neither motion pattern was recognizable by itself under these viewing conditions, and neither pattern was intrinsically more attractive. In the upright condition, however, the infants looked longer at the novel display. The experiment provides evidence that infants discerned the structure in the pattern of animate motion. It is possible that the presence of this structure led them to perceive the animately moving dots as a unitary human face.

In summary, these experiments suggest that infants first perceive two-dimensional patterns, as well as three-dimensional objects, under conditions involving motion. Infants do not group pattern elements into units through an analysis of static gestalt configurations, just as they do not group surfaces into objects on this basis. Studies of preferential looking appear to converge on a single description of the organization of the infant's visual world.

Perception and Knowledge of Objects of Particular Kinds

As children gain knowledge about the world, they come to consider objects as members of certain kinds, with characteristic properties and functions, and knowledge about particular kinds of objects may enhance the child's ability to perceive objects. As adults, we often perceive objects by drawing on knowledge about the properties of objects of particular sorts. Knowledge about the characteristic shapes of spoons, for example, leads us to perceive the complete shape of a spoon that is partly hidden within a bowl of cereal; knowledge about cups leads us to perceive a cup as separate from the saucer on which it rests. If an infant's perception of objects is also affected by knowledge about particular categories of objects, then studies of object perception could serve as a means to investigate the development of such knowledge.

One experiment (Schwartz, 1983) has explored that possibility. Schwartz investigated infants' knowledge of the properties of human faces by using Kellman's procedure to probe their perception of partly hidden faces. Infants were presented with a slide photograph of the face of an unfamiliar woman, projected behind a horizontal block that occluded the center of the face. After habituation, infants were shown slide photographs of the complete face, and of a face with a gap where the occluder had been. If infants can recognize a partly hidden photographed face as a face, and if they know that a face is a connected object, then they were expected to generalize habituation to the complete face and not to the broken face.

The 5-month-old infants in Schwartz's first experiment appeared to perceive the face as a connected object. These infants looked relatively longer at the broken face than did a baseline group of infants who were presented with the test displays after habituation to an unrelated object. (There was a baseline preference for the complete face.) A second experiment was then conducted to investigate whether infants' perception depended on an analysis of the features of the face, or on an analysis of the simplicity of the face's overall shape. Five-month-old infants were presented with slide displays consisting of an abstract, spotted object with the same outline shape as the face, but with no other facial features. After habituation to this display under partial occlusion, infants showed less of a preference for a broken display than did the infants in the experiment with the photographed face. It appeared that perception of the partly hidden face in the first experiment depended, at least in part, on infants' knowledge of the features of the face.

A third experiment was conducted with younger infants to investigate the development of knowledge of faces. After habituation to the partly hidden photograph of a face, 4-month-old infants showed no looking preference for the broken test face, unlike their 5-month-old counterparts. It appears that knowledge of faces comes to influence infants' perception of a partly hidden face between 4 and 5 months of age. This finding complements the findings of other experiments on face perception, which suggest that sensitivity to the configurational properties of a face increases considerably during the fifth month of life (e.g., Caron, Caron, Caldwell, & Weiss, 1973).

In summary, infants of 5 months, like adults, can use knowledge of faces as a basis for perceiving a partly occluded face as a unitary, connected object. The emergence of this ability may depend on maturation of innate mechanisms for detecting facial configurations; face recognition has been shown to have certain maturational components (Carey, 1983). The emergence of this ability may depend, as well, on learning: Since infants are able to perceive objects under conditions involving motion, they would seem to be in a position to learn about objects that are often observed in motion, such as human faces. In any case, experiments using looking-time measures hold promise as tools for investigating the development of knowledge of faces and other kinds of objects.

Some Limitations of the Methods

Although experiments using preferential-looking methods appear to have shed light on infants' perception of objects, these experiments must inevitably confront two problems of interpretation. First, what justifies the inference that the test display preferred by infants in a given experiment is the more *novel* display? Might not infants, under some conditions, look systematically at a display that is more familiar? Second, even granting that infants perceive a given test display as more novel, what justifies the inference that this display is perceived to contain novel *objects*, with different boundaries from the objects in the familiar display? Might not infants perceive the more novel display to contain the same units as the familiar display, but in a different arrangement? These problems will be considered in turn.

To begin with the first problem, many investigators have suggested that infants do not tend to look longest at the most novel of a set of displays. Responses to novelty, it is suggested, are curvilinear, with extremely novel arrangements receiving less attention than moderately novel arrangements (Kagan, 1971; McCall, Kennedy, & Appelbaum, 1977; for a recent discussion, see Kagan, Linn, Mount, & Reznick, 1979). In one experiment (McCall et al., 1977), for example, 2- and 4-month-old infants were familiarized with one of four checkerboard patterns with elements of different sizes. The infants subsequently looked longer at a new checkerboard pattern with elements of a moderately different size than they looked at a pattern with elements of a greatly different size. In a second experiment, 2-month-old infants were habituated to a line drawing in one of four orientations. They subsequently looked longer when the same drawing was presented at a moderately different orientation than when the same drawing appeared at a greatly different orientation. In both studies, infants who became familiar with one display evidently looked longest to displays that were moderately different.

Investigators using novelty-preference methods must always be alert to the possibility that infants will prefer the more familiar, and not the more novel, test display. One cannot ever conclude that a given display is more novel from the results of one experimental condition considered alone. For example, consider by itself the principal condition of the moving, partly occluded rod study by Kellman and Spelke. After habituating to the partly hidden rod, infants might have looked longer at the broken rod not because they perceived the partly hidden rod as complete but because they perceived it as broken. The broken test rod might have commanded their attention because that rod was only moderately discrepant from the habituation display, whereas the complete rod was too discrepant. It is only by comparing infants' reactions across different experimental conditions that one becomes able to interpret this difference in looking times. When one considers the results of the preliminary studies of perception of partly occluded objects, for example, one discovers that infants looked longer at the display in which a new rod figure appeared, not at the display containing the original rod figure. It is unlikely that infants would show the opposite tendency in the principal experiments, whose displays and methods were so nearly the same. Moreover, when one considers the findings of the principal experiments, one learns that the introduction of movement leads to an increase in the preference for the broken rod. If these infants were exhibiting a preference for the more familiar display, one would have to conclude that the presence of common movement *detracted* from perception of a complete rod for infants. This possibility appears remote, since common movement has the opposite effect for adults and for other animals. The total pattern of experimental findings therefore provides strong evidence that infants looked longer at the more novel of the test displays.

The usefulness of preferential-looking methods would be greatly enhanced if investigators were able to predict, in advance, when infants will prefer the more novel of two objects. One such prediction may be possible in the future, for there is one generalization that appears to be true of all the experiments using this method. After familiarization with a display of objects, infants always appear to look longer when they perceive a novel object than they will look when they perceive only objects from the original display, in familiar or novel positions. To my knowledge, all of the studies that have reported a curvilinear relation of looking time to stimulus novelty have used test objects that were either all novel, as in the case of the four distinct checkerboards, or all familiar, as in the case of the pattern at four orientations. Given a choice among several novel objects, infants may not always look longest at the object that differs the most from objects with which they are familiar. Given a choice between a novel object and a familiar object, however, infants may consistently look longer at the novel object.

Let us turn to the second interpretive problem. How does one know that infants perceive certain familiar and novel *objects,* with internal coherence and external boundaries? One challenge to this interpretation arises from an extreme empiricist stance. Perhaps infants do not perceive objects at all, but only patterns of visual sensation. In situations where adults perceive changes in the boundaries of objects, infants may experience the greatest changes in sensory patterns. For example, the sensory experiences evoked by a moving occluded

rod may be more different from those evoked by the broken rod display than from those evoked by the complete rod display. Responses to sensory properties of these displays may underlie infants' looking preferences.

As many investigators have noted (see especially Gibson, 1969; Bower, 1972; Yonas & Pick, 1975), this question is not easily answered. Indeed, it will not be possible to test the sensory hypothesis fully until the sensory capacities of infants are better understood. Nevertheless, there are several ways to obtain evidence against the hypothesis. First, one can design individual experiments to be maximally biased against the hypothesis that infants perceive objects, by making the habituation display as similar as possible to the display of putatively novel objects, and as different as possible from the display of putatively familiar objects. Thus, Kellman's and Schmidt's broken test objects were designed to be nearly identical to the visible surfaces of the occluded objects. The findings of these experiments suggest, therefore, that infants responded to the objects and events themselves, and not directly to the sensory patterns to which these objects gave rise.

One can also obtain stronger evidence that infants respond to objects, and not directly to sensory patterns, by conducting a series of experiments that use different displays and that focus on a set of closely interrelated questions. Thus, the same methods have been used to investigate infants' perception of partly occluded objects, of adjacent objects, and of objects that are separated in depth. The conclusion that looking times in these experiments reflect infants' perception of objects is strengthened by the finding that all the patterns of preference can be accounted for in terms of a single, underlying tendency to group surfaces into units that are spatially connected and separately moveable. It is conceivable that all these findings could be explained in terms of a single, broad and general account of infants' sensory capacities. Such an account is difficult to imagine, however, and none has yet been proposed.

A further challenge to the interpretation of object-perception experiments arises from an extreme nativist position: How does one know that infants fail to perceive the unity of a partly hidden stationary object, or the distinctness of two stationary objects that are adjacent? Perhaps infants perceive objects under all the conditions that adults do, but they also attend to the configuration of objects in a scene, and they react to changes in this configuration. For example, infants who were habituated to two adjacent objects might have perceived two objects that were *adjacent.* When one object was displaced, these infants might have increased their looking not because they perceived a change in the boundaries of the objects, but because they perceived a change in the objects' relative positions: the objects were no longer adjacent. This last possibility has been tested through further preferential-looking experiments. Infants have been presented with a display of adjacent objects, and, in effect, they have been asked *how many units* were in the display.

When infants are presented with a visual display, they appear to enumerate the units in the display, provided that the total number of units is small. Evidence that infants are sensitive to number has come primarily from experiments using familiarization/novelty-preference methods. Infants have been presented with a succession of displays of forms, each display containing the same number of forms. After their looking time to these displays has declined, they are presented with new displays containing either the same number of forms or a different number of forms. Infants have been found to look longer at the displays that contained a new number of forms (Starkey & Cooper, 1980; Starkey, Spelke, & Gelman, 1980; Strauss & Curtis, 1981), even as newborns (Antell & Keating, 1983). This finding is of interest in itself, for it suggests that patterns of preferential looking are affected by changes in quite abstract properties of displays. For present purposes, however, the experiments are important because they provide a means to investigate infants' perception of visible objects.

One experiment (Prather & Spelke, 1982) will serve as an illustration. The experiment focused on infants' perception of adjacent and spatially separated objects. Infants of 3 months were presented with a succession of different displays of rectangular, solid objects. Although the objects in different displays were of different colors and dimensions, all the displays contained the same number of objects. For half the infants, each display contained one object; for the others, each display contained two objects that were separated in the frontal plane (Figure 9a). After looking time had declined to half its original level, infants were presented with new objects that were either adjacent, side by side, or were separated in depth (Figure 9b). The infants who had been presented with displays of one object generalized habituation to the adjacent-objects display and looked longer at the objects separated in depth. The infants who had been presented with the displays of two objects exhibited the opposite looking preference. All the infants, therefore, treated the adjacent objects as one unit, and the objects separated in depth as two units.

This experiment provides further evidence that patterns of preferential looking reflect, in part, infants' perception of objects and their boundaries. Infants perceive objects by grouping together surfaces that touch, but not by grouping together surfaces that form simple, regular configurations. Moreover, each perceived object is taken to be a unit that is countable, in some sense. All these experiments are consistent with the notion that infants have the capacity to organize the visual world into units that are internally coherent and separately moveable: the units that we as adults call "objects."

Infants may perceive objects by virtue of perceptual mechanisms that are specific to vision. Alternatively, they may perceive objects by virtue of an abstract and general conception of the material world and its organization. Infants may have the notion that the world divides into things that are spatially connected, bounded, and coherent: things that can move independently but that must move as wholes. We will return to these two possibilities after considering two more bodies of research: studies of how infants perceive objects that are sensed through two sensory modalities at once, and studies of how infants understand events in which objects move wholly from view.

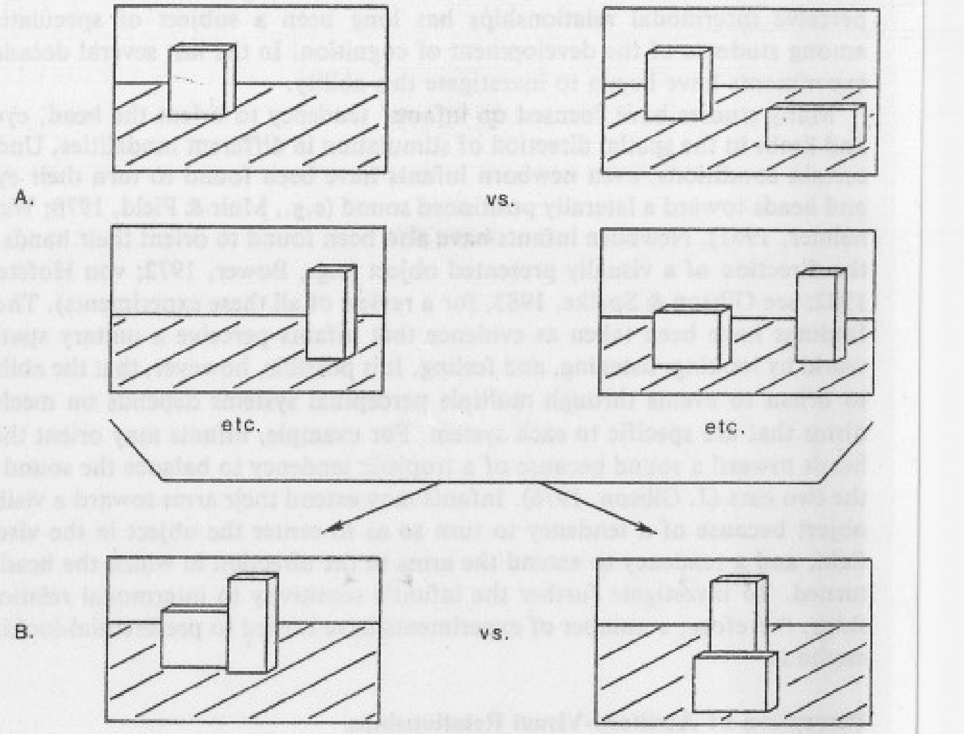


Figure 9. Schematic depiction of (*a*) some habituation displays and (*b*) the test displays of an experiment on enumeration of adjacent and spatially separated objects (Prather & Spelke, 1982).

LOOKING AT SOUNDING OBJECTS: AN INDEX OF KNOWLEDGE OF INTERMODAL UNITY

Human adults do not live in a world of sights and sounds and tactile sensations, but a world of objects and events. When they look at an event while hearing its sound, for example, adults perceive a unitary episode. Perception of the unity of objects and events that are seen and heard depends on an ability to detect intermodal relationships: to determine when an object that is seen, and an object that is heard, are one and the same.

This ability is of considerable interest to those who study human knowledge. Since each sensory system is quite different in and of itself, the perception of intermodal relationships would seem to depend on abilities to apprehend rather abstract properties of the world. An adult's ability to perceive relationships between the diverse sounds that compose a symphony and the instruments that produce each sound, for example, appears to depend on his or her knowledge of music and its production (Pick, 1983). Because of the apparently close tie between intermodal perception and knowledge, the infant's ability to perceive intermodal relationships has long been a subject of speculation among students of the development of cognition. In the last several decades, experiments have begun to investigate this ability.

Many studies have focused on infants' tendency to orient the head, eyes, and limbs in the spatial direction of stimulation in different modalities. Under certain conditions, even newborn infants have been found to turn their eyes and heads toward a laterally positioned sound (e.g., Muir & Field, 1978; Wertheimer, 1961). Newborn infants have also been found to orient their hands in the direction of a visually presented object (e.g., Bower, 1972; von Hofsten, 1982; see Gibson & Spelke, 1983, for a review of all these experiments). These findings have been taken as evidence that infants perceive a unitary spatial world by looking, listening, and feeling. It is possible, however, that the ability to orient to events through multiple perceptual systems depends on mechanisms that are specific to each system. For example, infants may orient their heads toward a sound because of a tropistic tendency to balance the sound at the two ears (J. Gibson, 1976). Infants may extend their arms toward a visible object because of a tendency to turn so as to center the object in the visual field, and a tendency to extend the arms in the direction in which the head is turned. To investigate further the infant's sensitivity to intermodal relationships, therefore, a number of experiments have turned to preferential-looking methods.

Perception of Auditory-Visual Relationships

The first experiment of this kind, to my knowledge, investigated whether 4-month-old infants can ever determine if an event they see and an event they hear are one and the same (Spelke, 1976). When babies look and listen to one event, do they perceive what they hear as related to what they see? When they look at one event while listening to another, do they perceive that what they see is distinct from what they hear? To address these questions, infants were presented with two filmed events, side by side. One event consisted of a woman playing "peekaboo," and the other consisted of a hand holding a baton and hitting two percussion instruments in a simple rhythmic pattern. While the events were projected side by side, the soundtrack to one film was played through a central speaker. If infants perceived that the voice went with the person and the percussion music went with the instruments, they were expected to look longer at each event when its corresponding sound was played.

Why might one expect infants to explore so as to focus on one event at a time? When we as adults listen to one of several objects, we generally look at that object in preference to other objects because of two perceptual effects. First, adults usually see an event better if they can also hear it, and they hear an event better if they can also see it. This effect is apparent, for example, when one watches a symphony on television: the sound of the violins is more distinctive when the camera focuses on them than when it focuses on the wind

instruments. Second, adults attend better to one audible event in a stream of sounds, avoiding distraction, if they also follow that event by looking (e.g., Reisberg, 1978). Given the apparent limits on infants' abilities to perceive and attend to events, it seemed likely that they would be especially apt to look at events to which they listen.

The results of this experiment were clear: Infants looked longer to the peekaboo game when they heard the voice sound, and they looked longer to the percussion instruments when they heard the percussion sound. Since that study, this looking pattern has been observed by a variety of investigators using a variety of events, and it has provided evidence that infants detect a number of different auditory-visual relationships. Infants of 4½ months, for example, have been found to detect relationships between the sight and sound of a xylophone, a hand clap game, and a rattling slinky toy. When two of these events are presented side by side, infants looked longer at the event projected in sound (Bahrick, Walker, & Neisser, 1981).

How do infants determine which of two visible events is the source of an accompanying sound? Since the sounds in all the events occurred in temporal synchrony with certain movements of the visible objects, it is possible that infants perceived the sound-object relationships by detecting this pattern of synchrony. To investigate this possibility, a variety of experiments have presented infants with unfamiliar inanimate objects, each of which moved in synchrony with a different percussive sound. For example, infants have been presented with two stuffed animals that bounced on a surface, each bounce occurring at the time of a dull or a reverberant percussive sound. Infants of 4 months were found to detect this sound-object relationship: when both objects were presented, accompanied by one of the sounds, infants looked longer at the object that moved in time with the sound (Spelke, 1979). Subsequent experiments (Spelke, Born, & Chu, 1983) revealed that 4-month-old infants detect the synchrony of a sound with any change in the movement of an object, whether or not a visible impact occurs. In this respect, infants differ from adults. For example, if adults are presented with a sound, and they simultaneously see one object hitting a surface and another object stopping in midair, they perceive the sound as related to the former object. Infants, in contrast, looked equally at the impacting and the nonimpacting objects under this condition. This study and others (see Spelke et al., 1983) provide evidence that infants relate sounds to an object by detecting the object's pattern of movement. Unlike adults, they do not relate percussive sounds specifically to moments of impact.

If infants can detect the synchrony of sounds with visible object movements, they might be able to perceive a unitary object when they look and listen to a speaking person, for voices are synchronized with facial movements during human speech. A number of experiments confirm that 3- to 5-month-old infants detect the synchrony of audible speech to visible facial movements. Infants who were presented with one voice accompanied by two faces, one of which was synchronized with the voice, looked longer at the appropriately speaking face. The preference has been found both in experiments using the standard preference method, in which one voice is played between two faces that are side by side (Spelke & Cortelyou, 1981; Walker, 1982), and in experiments in which one face is presented at a time, accompanied by a synchronized or a nonsynchronized voice (Dodd, 1979).

In summary, infants can perceive the unity of many events in which objects are seen and heard. They perceive intermodal relationships, at least in part, by detecting the synchrony of visible speech and audible speaking movements. The ability to perceive intermodal relationships was revealed through infants' patterns of preferential looking: Infants tend to look at an event that corresponds to an accompanying sound, following that event by looking and listening at once. This pattern of exploration is likely to foster the development of knowledge about the perceptual world. An infant who looks and listens to an object at once is in a position to learn about the particular sounds that are characteristic of that particular object. As infants gain such knowledge, they should become able to perceive relationships between sounds and objects even under conditions in which the synchrony of sounds and movements cannot guide them. We turn now to experiments that focus on infants' knowledge of particular auditory-visual relationships. These experiments illustrate that auditory-visual preference methods can shed light on the infant's developing knowledge of objects and their characteristic sounds.

Knowledge of the Properties of Sounding Objects

The most familiar audible and visible objects in a young infant's world are probably the infant's parents. Infants often have the opportunity to look at a parent while the parent speaks to them, and the research described above suggests that infants will tend to do this systematically (see also Haith, Bergman, & Moore, 1977). It is of interest, therefore, to discover when, and under what conditions, children learn that each parent's face and voice go together.

This question has been addressed through an experiment that used a variant of the preferential-looking method described in the last section: what we have called a "search" method (Spelke & Owsley, 1979). When adults hear a sound very briefly, and they know what visible object is characteristically the source of that sound, they will often look for the object. Adults may look for a certain person when they hear a familiar voice or familiar footsteps, and they may look for a certain kind of animal if they hear a familiar growl. Although adults do not always look for the sources of sounds, especially in a noisy environment in which the same sounds are repeated, they generally do look for the sources of sounds that are new, sudden, or unexpected. They do this by drawing on knowledge about the sounds and the visible appearances of objects. Accordingly, the experiment with infants investigated whether infants would also turn to look at a familiar object (in this case, the mother or father) when they heard its characteristic sound (the parent's voice).

Infants of 3, 5, and 7 months of age were seated facing the mother and father, who sat side by side and faced the child without moving. After an infant's gaze was drawn between the parents, one parent's tape-recorded voice was played for a few seconds through a central speaker, and the infant's subsequent looking was observed. A series of trials were given, half with each parent's voice. The infants tended to turn to look at the parent whose voice was played: they turned first to the appropriate parent on reliably more trials than they turned to the inappropriate parent. The effects were not large: no infant turned first to the appropriate parent on every trial, and most only looked consistently to the appropriate parent on a short string of trials. (Note that when the infants turned, they encountered a motionless and unresponsive person.) Nevertheless, the looking pattern was reliable. It showed that infants as young as 3 months have learned something about the relation between each parent's voice and face.

The search method has proven useful in studies of the process of learning about intermodal relationships. Infants of 4 and 6 months have been presented with one moving, sounding object during a brief period of familiarization. Then they were shown that object and a second object, both accompanied by the sound, and their looking times to each object were recorded. Infants were found to look more at the object that corresponded to the sound (Lyons-Ruth, 1977; Lawson, 1980; Spelke, 1981). They had evidently learned, over the course of the familiarization period, that the sound and object were related.

The search method has been used to assess infants' knowledge of other properties of objects, such as their rigidity or flexibility. Bahrick (1980) presented 4½-month-old infants with either a clacking or a squishing sound, and then she presented silent films of squishing sponges and clacking blocks side by side. The sounds and films appeared on a series of brief trials. Infants tended to look first to the event that corresponded to the sound. Bahrick suggested that they perceived the rigidity or flexibility of the objects both by looking and by listening.

Similar methods have also been used to investigate infants' knowledge of the relationships between particular audible speech syllables and the particular visible gestures that produce them (Kuhl & Meltzoff, 1982; MacKain, Studdert-Kennedy, Spieker, & Stern, 1983). Infants of 4 or of 5-6 months were shown two videotapes, side by side, of a woman producing one of two syllables repeatedly. The videotapes were synchronized with each other, and both were synchronized with an accompanying speech sound that corresponded to one of the two syllables. Infants tended to look longer at the videotape of the face whose articulatory gestures corresponded to the speech sound.

Finally, preferential-looking experiments have investigated infants' sensitivity to the emotional tone of an expressive face (Walker, 1982). Infants of 5 and 7 months were presented with two films of a face expressing different emotions: happiness, sadness, anger, or a neutral expression. These films were accompanied by a voice with the same emotional tone as the expressions in one of the films. This voice, however, was not synchronized with either film, so only the common emotional tone of the face and voice tied them together. At first, infants showed no preference between the films, perhaps because they detected the asynchrony of the voice with both faces. After about 1 minute, however, infants began to look longer at the face whose expressions corresponded in tone to the voice. Infants of 5 months appear to be sensitive to information for a speaker's emotional tone.

Knowledge of Number

In the above studies, the tendency to look at an event corresponding to a sound has been used to investigate infants' perception and knowledge of events taking place around them. But this tendency can also serve to shed light on infants' knowledge of more abstract properties of the world. Wagner, Winner, Cicchetti, and Gardner (1981) present evidence that a group of infants aged 6-14 months looked preferentially at an object that adults judge to be metaphorically related to a sound; they suggest that studies of preferential looking can gauge infants' representations of figurative relations among events. Starkey, Spelke, and Gelman (1983) present evidence that 6- to 8-month-old infants look preferentially at a display of objects that corresponds numerically to a series of sounds; this evidence suggests that preferential looking can be used to investigate early representations of number. I will focus on the latter finding.

As we have noted, experiments using familiarization/novelty-preference methods have revealed that infants are sensitive to the number of objects or forms in a visual scene. These studies suggested that the infants were able to enumerate the units in the scene, arriving at a representation that captured numerical information. One could question, however, whether infants were truly sensitive to number. Since only visual displays were presented, it is possible that a visual mechanism sensitive to certain complex properties of spatial patterns underlay infants' discriminations. If this were the case, one would hesitate to grant infants any knowledge of number, for number concepts are abstract and amodal.

Accordingly, experiments were conducted to determine if 6- to 8-month-old infants are sensitive to numerical correspondences across the auditory and visual modes. The experiments used a variant of the auditory-visual preference procedure. Infants faced a screen on which two photographic slides were displayed side by side, one depicting two objects and one depicting three objects. After 2 seconds, they heard either two or three drumbeats from a central location. The slides remained in view for 10 seconds after the last drumbeat, and infants' looking preferences between them were assessed. A series of such trials were given, half with two sounds and half with three sounds. In four separate experiments, infants tended to look at the display whose number corresponded to the number of sounds (Starkey et al., 1983). It appears that infants detect number both by listening and by looking, when they are presented either with a temporally extended event or with a spatially extended array of objects.

These experiments reveal that infants are sensitive to the number of objects in a scene and to the number of events in a sound stream, and that their sensitivity to number is reflected in a pattern of preferential looking that is quite similar to that observed in studies of perception of audible and visible events. Infants tend to look at a display of forms that matches, in number, a sequence of sounds. Experiments using preferential-looking methods can be used, therefore, to assess infants' knowledge of at least one abstract property of the world.

Selective Visual Attention

This section closes with one final illustration of the usefulness of auditory-visual preference experiments for studies of infants' cognitive abilities. Such exploration has been found to shed light on the infant's capacity for selective visual attention. In studies of human adults, Neisser and Becklen (1975) first discovered a visual capacity analogous to the capacity for selective auditory attention: just as adults can attend to one of two simultaneously spoken messages, they can attend to one of two simultaneously visible events. Adult subjects were presented with two distinct events—a hand clap game and a basketball game—overlapping on a video screen. The subjects were able to follow either of these events, and they were subsequently found to be unaware of almost everything that went on in the other event.

Does selective visual attention depend on skills that children acquire slowly, or does the capacity to attend selectively emerge at an early age? To address this question, Bahrick et al. (1981) investigated "selective looking" in 4-month-old infants, using a preferential-looking technique. Infants were presented with two events—a hand clap game and a flapping toy butterfly—in full overlap. While the events were projected simultaneously, the sound track to one event was played. If infants are able to follow either of these events selectively, they were expected to attend to the event projected in sound, and thus to perceive that event better than the silent event. A subsequent test for the relative novelty of the two events was given to determine if the infants had indeed attended to the sounding event: if they had, they were expected to look longer at the event they had not followed. The experiment provided evidence that infants did attend selectively to the event projected in sound: they subsequently looked longer at the other event. This study revealed that young infants can attend selectively to one of two overlapping visual events. Once again, infants attended to the event that corresponded to an accompanying sound.

Some Limitations of the Methods

Studies of preferential looking have shed light on infants' perception of a unitary event by looking and listening, their knowledge about the properties of particular audible and visible objects, their sensitivity to number, and their capacity for selective attention. The preferential-looking methods have, however, two drawbacks. First, infants do not always exhibit a visual preference for a sound-related event, even in circumstances for which there is evidence that infants detect the auditory-visual relationship. Second, even when infants do look preferentially at an object that corresponds to a sound, one cannot be certain that they perceive a *unitary*, sounding object. We will consider each of these limitations in turn.

There are at least two different situations in which infants fail to exhibit a visual preference for a sound-related object. First, young infants do not look longer at a speaking person when presented with the mother and a female stranger. Second, infants do not look longer at one of two sounding, inanimate objects when the objects are very similar.

In a number of experiments, infants have been presented with the voices and faces of the mother and a second unfamiliar woman, and the effects of each woman's voice on looking at her face have been assessed. Cohen (1974) and Spelke and Owsley (1979) used versions of the search method to investigate whether infants would look at the mother when her own voice was played and at the stranger when the unfamiliar voice was played. Cohen obtained this pattern at 8 months of age but not at 5 months. Spelke and Owsley obtained the opposite pattern at 4 months of age: infants looked more at the mother when they heard the stranger's voice than when they heard the mother's own voice. The presence of a reverse effect in this latter study suggests, albeit weakly, that infants do know about the characteristic face and voice of the mother, and evidence in favor of this suggestion comes from studies of even younger infants, who have been shown to recognize the mother's face (Barrera & Maurer, 1981) and voice (DeCasper & Fifer, 1980). Nevertheless, infants fail to look appropriately to the mother or stranger when they hear each person's voice. Perhaps the presence of the stranger herself accounts for this failure. When she speaks, her overtures to the infants may be slightly puzzling or disturbing, and the infants may turn to the mother for reassurance. This speculation has not, however, been explored.

The second situation in which appropriate preferential looking is not consistently observed is of greater interest for the present discussion, for it harkens back to the first exploratory pattern that we have discussed. Infants may sometimes fail to look at a sounding object because they have a countervailing tendency to explore events that are new or unexpected. These tendencies may come into conflict when infants are presented with events in which simple objects behave in similar ways.

For example, a variety of experiments have investigated infants' sensitivity to the synchrony of sounds with the visible impacts of moving objects (Bahrick, 1980; Spelke, 1979, 1981; Spelke et al., 1983; see also Humphrey & Tees, 1980). In these studies, 4-month-old infants were presented with two objects differing in shape and color but composed of the same substance, such as two puppets. A different percussion sound was paired with each object: sounds were chosen so that the two sounds differed in pitch, but either could have been produced equally well by either object. While infants viewed the two objects moving out of phase, they heard the sounds in succession. Each sound was synchronized with one of the objects and not synchronized with the other

object. Infants were found to detect the sound-object relationships, as evidenced by their performance on a subsequent search test: they tended to turn briefly toward each object when its synchronized sound was played. During the preference episode, however, clear and appropriate looking preferences were not always observed. There was a preference for the synchronized objects in some studies. In other studies using the same methods and displays, however, there were no reliable preferences. And in two experiments (see Bahrick, 1980; Spelke, 1981), there was a preference for the nonsynchronized object. This last effect was not replicated in subsequent research (Bahrick, in preparation; Spelke, 1981).

Why were the predicted preferences not observed? First, the events in these studies were simpler, more redundant, and less interesting than those in the studies previously described. Thus, the infants in these studies may have been prey to two conflicting tendencies: a tendency to explore one event at a time by looking and listening, and a tendency to explore two simple events at once. After discovering the auditory-visual relationship, some infants might have preferred the silent object because it was relatively new: it is not the object to which they had been listening. A tendency to seek change or novelty may then act against the tendency to look at the event one is hearing.

The results of certain studies of intermodal perception support this explanation. In a number of experiments, infants have been allowed to hear, to mouth, or to manipulate an object without seeing it, and then their visual preferences between that object and a second object were assessed. If the original period of familiarization was long, the infants in some experiments exhibited a visual preference for the novel object: the object they had not previously explored by listening or touching. This preference has been observed in studies of visual-haptic perception with infants ranging in age from 1 month (Gibson & Walker, 1982) to 1 year (e.g., Gottfried, Rose, & Bridger, 1977). It has also been observed with 4-month-old infants in studies of auditory-visual perception, in which infants were habituated to a sound and then presented with a corresponding and a noncorresponding object (Spelke, 1981). Novelty preferences are not always observed in experiments using this method (see Meltzoff & Borton, 1979, and Ruff & Kohler, 1978, for experiments in which the reverse effect was obtained). Nevertheless, the fact that a novelty preference is sometimes obtained suggests that the tendency to look at something one hears may be counteracted by a tendency to look at something new.

A second reason for the inconsistent preferences may also be offered. Inconsistent preferences have been observed only in experiments in which infants were presented with two very similar visible events, either of which could have been the source of a noise with the quality of the sound accompaniment. As the sound was played, moreover, there were occasional accidental conjunctions between its occurrence and the movements of the nonsynchronized object. If adults are given the same displays and asked to watch the nonsynchronized object, they do not perceive that object as fully independent of the sound, but report instead that the sounds and the object's movements are synchronized at some times and not synchronized at other times. This perception may reflect adults' tendency to perceive patterns of contingency among events even when no true contingency exists (e.g., Jenkins & Ward, 1965).

I suggest that the infants in the experiments with simple, synchronized objects may also have perceived each nonsynchronized object as somewhat related to the accompanying sound. Because this relationship is not perfect, it may have been especially intriguing to the infants. Along with the tendency to look at an object that moves and sounds in perfect synchrony, infants might have a competing tendency to explore an imperfectly synchronized object in order to investigate its relationship to the sound.

The results of an experiment by Bahrick and Watson (1983) are consistent with this possibility. The experiment investigated young infants' perception of the relationship between the sight and the feeling of their actively moving legs. Three-month-old infants sat facing two video screens. One screen presented a synchronized image of the infant's own moving legs and the other presented a videotaped, nonsynchronized image of another infant's moving legs, clothed so as to resemble the infant's own legs. Both visual attention and leg movements were observed. It was found that the infants moved their legs quite extensively, more than would have been expected without the visual displays. Moreover, infants showed a reliable preference for the video image of the legs that were not their own. This preference, and the increased leg movement, may reflect infants' efforts to test and discover the relation between their own movements and those of the legs that looked like their own legs, that moved in the same manner as their own legs, but that did not move in full synchrony with their own movements. The tendency to explore similar, nonsynchronized events may have prevailed over the tendency to look at an object that is perfectly synchronized with one's actions.

In brief, infants may sometimes fail to look preferentially at a sounding object because of either of two exploratory tendencies. First, infants tend to look at events that are novel, such as a moving object that differs from the sound they have been hearing. Second, infants may tend to look at events that are puzzling or problematic, such as a moving object that bears an uncertain relationship to an accompanying sound. These tendencies, of course, were the focus of the first half of this chapter: They provided the basis for all the studies of infants' perception of visible objects.

The second limitation of preferential-looking methods as a means to study infants' knowledge of intermodal relationships is more serious. Such experiments provide evidence that infants detect some relationship between a sound and a visible object, but they do not indicate *what kind* of relationship the infants perceive. I have suggested, for example, that infants perceive a unitary event when they look and listen to a speaking person. It is possible, however, that infants do not perceive one event in this case, but two separate events that are related; infants may perceive the face and the voice of a speaking person as

distinct events that are correlated. Infants may look longer at an object, when they hear its sound, not because of any tendency to follow single, unitary events by looking and listening simultaneously, but because of a tendency to look at one event while listening to a second event to which it is related.

The findings of the experiments on sensitivity to number and sensitivity to metaphor lend credence to the latter possibility. It is unlikely that infants perceive three drumbeats as the same event as three stationary objects: indeed, the objects are not events at all. Infants probably perceived the objects and the drumbeats as distinct but as corresponding in number. What, therefore, do infants perceive when they look and listen to a single moving and sounding object: one object or two?

No experiment, to my knowledge, has answered this question. The question could be addressed, however, through further experiments using preferential-looking methods. Number-detection techniques might be used, for example, to investigate whether infants perceive an object that moves and makes a noise as one event or two. Alternatively, it might be possible to investigate infants' perception of visible, sounding objects by making use of a striking perceptual phenomenon experienced by adults: the "ventriloquism effect."

When adults look and listen to one event, they tend to localize the event in a single position in space, even if a sound and its corresponding object are separated. When adults watch a film or a ventriloquist's performance, for example, the sound of each object is spatially displaced from its visible source, but it is heard as coming from the direction of the appropriate object. This bias in perception occurs only when adults make the assumption that the object they see and the object they hear are one and the same (Welch & Warren, 1980). Adults tend to perceive all sources of information about an object as coming from a single position in space, but only when they believe that the sounds they hear emanate from the object they see.

It might be possible, therefore, to investigate infants' perception of the unity of an object by asking whether infants experience a ventriloquism effect. This question could be addressed, in turn, by means of a preferential-looking experiment. On a series of trials, infants could be presented with a filmed object and a sound that is displaced from the object to various extents. Their tendency to look away from the object, in the direction of the sound, could serve as an index of their ability to detect that the sound and object occupy different positions. In one condition, the sound and the filmed image would be unrelated; in the other condition, they would specify a unitary object. If infants perceive unitary objects by looking and listening, then they should be less sensitive to the spatial separation between the sound and object when they form a unitary episode. At a wider range of displacements, the unitary sound and object should be localized in the same place.

A preliminary experiment with 5-month-old infants suggests that this preferential-looking technique can be used to assess infants' localization of the displaced sound (Nachmias, Spelke, Termine, & Shepperson, unpublished observations). We do not yet know, however, whether infants experience a ventriloquism effect when they look and listen to a single object.

LOOKING AT NOVEL EVENTS: AN INDEX OF KNOWLEDGE OF PHYSICAL CAUSALITY

Human adults experience a world of material bodies that behave in conformity with physical laws. We, as adults, have knowledge about the behavior of material objects, and we use this knowledge whenever we act on objects, trace objects through time, and make predictions about an object's future states. For example, we know that objects tend to persist when they move, even if they move out of view. When an object moves freely, we predict that it will continue to exist throughout this movement. We also know that objects tend to move on certain trajectories, that they will only tend to change their pattern of movement if they come in contact with some other body, and that they are subject to gravity and will fall to the ground if they are not supported in some way. This knowledge aids us in predicting the future positions of an object, and it allows us to infer, from changes in an inanimate object's movements, what interactions with other objects have taken place.

It is again Piaget (1954) who began the systematic study of the development of these and other physical notions. Piaget focused on the ability of infants to act on objects in a systematic manner. He studied infants' developing ability to search for objects that are out of view by removing or reaching around their occluders, and infants' developing ability to apprehend distant objects by pulling toward themselves some nearer object that supports or connects with them. These abilities, Piaget found, develop quite slowly over the course of infancy. In particular, young infants do not seem to search in any way for objects that leave their view. Piaget, like many of his successors (see Harris, 1983), concluded that human notions of material bodies are constructions: Humans have no initial conceptions of objects and their behavior.

The reliance on search behaviors as indices of infants' conceptions of objects, however, has drawbacks. A young infant's failure to search for hidden objects could reflect the immaturity of the capacity for coordinated search itself, rather than the absence of a notion that objects are persisting. Two kinds of experiment provide evidence for the latter view. First, investigations of search behavior have revealed that infants come to locate objects using one kind of activity—visual tracking—before they come to locate objects in other ways, by reaching or crawling to an object (see Harris, 1983, for a review). Second, Piaget's studies of the development of coordinated activity have revealed that, in general, infants under about 8 months fail to coordinate any distinct actions into means-ends sequences (Piaget, 1952). The absence of this coordination would seem to provide a sufficient explanation for infants' failure to search for hidden objects, irrespective of infants' conceptions of those objects. Searching requires that one perform one act (e.g., removing a cover) in order to make possible the performance of future acts (e.g., obtaining an object), and this feat appears to be beyond the capacities of a young infant.

The experiments reviewed in the first section provide a further reason for questioning Piaget's theory of the development of conceptions of objects. Those experiments provide evidence that infants perceive partly hidden objects before they are capable of acting upon the objects effectively, contrary to Piaget's theory. It is important, therefore, to investigate infants' knowledge of the persistence of hidden objects using methods that do not rely on search. Recently, a number of psychologists have begun to undertake studies of infants' conceptions of the behavior of material objects by using preferential-looking techniques. These studies suggest that some conceptions of objects and of material causality are present at an early age.

Knowledge of the Causes of Object Movement

Several experiments have investigated infants' understanding that one inanimate object cannot act upon another at a distance, so as to set the second object in motion. Ball (1973) presented children ranging in age from 2 months to 2 years with two objects that moved behind an occluding screen (Figure 10a). One object approached the screen from the left, and moved behind it so that the object was fully occluded. Then the second object moved into view from behind the screen, on the right. The second object moved into view at the time, and at the speed, at which it would have moved if the first object had hit the second while it was stationary and had thereby set it in motion. Adults have been found to perceive a causal relationship between the movements of two

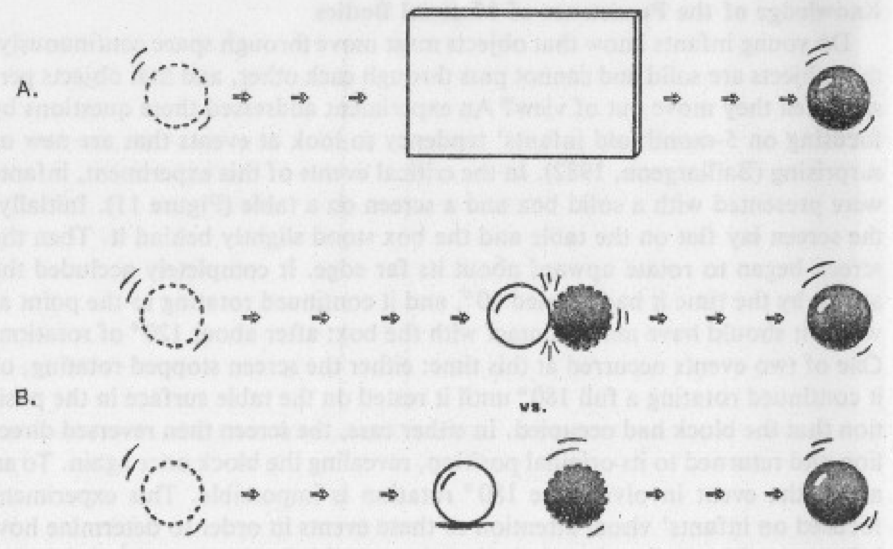


Figure 10. Schematic depiction of (a) the habituation display and (b) the test displays of an experiment on knowledge of causal relationships (Ball, 1973).

such objects: the first object is perceived to contact the second and set it in motion (see Michotte, 1963). To investigate infants' perception of this event, Ball presented the event on repeated trials, until infants' looking time had declined. Then he removed the occluder and presented two events on alternating trials. In one event, the first object hit the second, as an adult would expect. In the other event, the first object halted before making contact with the object, and the second object began to move on its own (see Figure 10b). Infants looked longer at the latter event. It appears, therefore, that they had inferred that the first object made contact with the second object behind the screen.

Ball's experiment provides evidence that infants know an inanimate object will not change its pattern of movement unless it comes into contact with other objects. Additional support for this conclusion is provided by two experiments by Leslie (1982), using a similar familiarization/novelty-preference method. Infants of 4½ and 8 months were presented with events in which a hand picked up an inanimate object, or in which one moving inanimate object set another object in motion. In different conditions, the two objects in these events either made contact or failed to make contact. Infants' looking preferences suggested that they expected the second object in each event to move only if it made contact with the first.

Ball's experiment also provides evidence that infants perceive objects to persist when they are out of view, since the infants generalized habituation from an event in which two objects were alternately visible and invisible to an event in which the two objects were visible continuously. Additional support for the latter conclusion comes from the last preferential-looking experiment to be described.

Knowledge of the Persistence of Material Bodies

Do young infants know that objects must move through space continuously, that objects are solid and cannot pass through each other, and that objects persist when they move out of view? An experiment addressed these questions by focusing on 5-month-old infants' tendency to look at events that are new or surprising (Baillargeon, 1982). In the critical events of this experiment, infants were presented with a solid box and a screen on a table (Figure 11). Initially, the screen lay flat on the table and the box stood slightly behind it. Then the screen began to rotate upward about its far edge. It completely occluded the screen by the time it had rotated 60°, and it continued rotating to the point at which it should have made contact with the box: after about 120° of rotation. One of two events occurred at this time: either the screen stopped rotating, or it continued rotating a full 180° until it rested on the table surface in the position that the block had occupied. In either case, the screen then reversed direction and returned to its original position, revealing the block once again. To an adult, the event involving the 180° rotation is impossible. This experiment focused on infants' visual attention to these events in order to determine how infants would perceive them: whether they would also represent the occluded block as continuing to exist, and whether they knew that the presence of this block should constrain the movements of the screen.

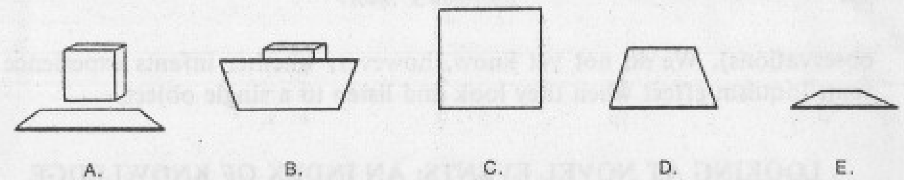


Figure 11. Schematic depiction of the test displays of an experiment on knowledge of the persistence of a hidden object. The screen moved from *a* to *d* (possible event) or from *a* to *e* (impossible event) (Baillargeon, 1982).

To assess infants' reactions to these events, the events were embedded in a familiarization/novelty-preference experiment. Infants were presented repeatedly with a display consisting only of the rotating screen. The screen rotated back and forth 180° about one of its edges. On each of a series of trials, this display was presented for as long as the infants would look at it. After looking times on successive trials had declined by half, the box was placed behind the screen in the path of its rotation. To familiarize infants with the box, it was presented behind the screen with no movement for two trials. Then infants were presented with the two events described above, in alternation, for six test trials. On each trial, an event was presented repeatedly until the infant looked away, and the infant's looking time was recorded. A subsidiary experiment had indicated that 120° and 180° rotations of the screen are of equal intrinsic interest to infants of this age, if they occur in a situation in which both events are possible.

The experimental predictions were as follows. If 5-month-old infants do not represent the existence and the location of a hidden object, then habituation should generalize more to the 180° test rotation: this was the very pattern of movement to which infants had been habituated. If, however, infants know that a hidden object persists in a definite location when it is out of view, and if they know that one object cannot pass through the space occupied by another, then they should look longer at the 180° rotation than at the 120° rotation, for two reasons. First, the 180° rotation should be seen as more novel, since the screen passed through space occupied by an object in that condition, whereas, in the habituation condition and in the 120° test conditions, the screen moved unimpeded and stopped when it hit an object or surface. Second, the 180° rotation should be seen as puzzling or surprising, since the event that it depicts is impossible: one object cannot pass freely through a place occupied by another object.

The findings were clear: infants looked longer to the impossible 180° rotation. This finding provides evidence that 5-month-old infants know that an object persists in a definite place when it is out of sight, and that the location of an invisible object limits the possible movements of a visible object. Moreover, the experiment indicates that infants reveal what they know about objects through their patterns of preferential looking to events, even at an age at which such knowledge is not revealed through their patterns of search. In this experiment, infants did not habituate and dishabituate to the surface appearance of a visual display but to the underlying configuration of objects that they knew to be present in the display. Surely, a 180° rotation is superficially more similar to itself than to a 120° rotation. After habituation to a 180° rotation, however, infants reacted to the impossible 180° rotation in the test as if it were new or surprising, and to the possible 120° rotation as if it were relatively familiar or expected. In studies of infants' knowledge of fully occluded objects, as in the earlier studies of perception of partly occluded objects, infants' looking patterns appear to be influenced most by properties of the perceived objects themselves, not by properties of the configuration of surfaces that are visible. Studies of preferential looking thus would seem to provide a promising tool for future investigations of infants' knowledge of objects and physical causality. The tendency to explore displays that are new or surprising can be used to investigate what infants perceive and know.

Limitations of These Methods

The two major problems that arise in these experiments are the same problems that arose in the experiments on infants' perception of objects. First, infants may not always look longer at the more novel or surprising of two displays. The existence of a looking preference between two events does not indicate, by itself, which event is taken to be more surprising. Second, even if one could be certain that longer looking indicated surprise, one cannot be sure that this preference reflects any systematic knowledge about material objects and their behavior. The more novel or more surprising event may be more novel or surprising for reasons that are unrelated to any conceptions about objects and pertain, instead, to sensory properties of displays.

I will not dwell on the solutions to these problems, for they are the same solutions discussed before. Both problems can only be addressed by comparing infants' reactions to a variety of stimulus displays, across a variety of experimental conditions. In the experiments described above, a number of displays were presented in order to assess the possibility that infants preferred the more familiar event and the possibility that infants reacted to sensory characteristics of the displays. Nevertheless, investigators of infants' notions of physical objects and physical causality have hardly begun to study systematically infants' diverse reactions to different causal events. This enterprise should occupy the efforts of students of infant cognition in the coming years.

CONCLUSION

In summary, infants are apt to show two patterns of visual exploration. They tend to look at events that are relatively novel and perhaps unexpected, and they tend to look at events that they also hear. Experiments that focus on these looking patterns suggest that infants have basic notions that allow them to perceive objects, events, and the causal relations within and among events. Such experiments also suggest that infants have certain capacities to perceive speech sounds, to enumerate objects, to detect expressions of emotion, and to

recognize human faces. Patterns of preferential looking suggest that infants do not have all the means of perceiving and apprehending objects that we have as adults: infants do not perceive objects by analyzing their static configurational properties, for example, and they do not perceive sounding objects by relating sounds to moments of visible impact. These differences between infants and adults begin to suggest how human conceptions change with development: how concepts grow as children mature and learn.

Concerning the limitations of preferential-looking measures, the same two problems have arisen in every domain in which these methods have been applied. One problem is essentially practical: investigators cannot confidently predict, in advance, whether infants will exhibit a preference for the more novel or for the more familiar of two events, and whether infants will prefer an object that corresponds to a sound or one that does not. Until psychologists understand the conditions under which these preferences are obtained, they will need to incorporate a variety of control conditions into their experiments to determine which pattern of preference is observed in a given experimental situation.

The second problem is deeper: How can experimental psychologists discover what an infant perceives and knows? How can one ever find out whether infants perceive objects or patterns of sensation, unitary multimodal events or separate but related sights and sounds, objects interacting according to principles of physical causality or sensory patterns occurring in certain conjunctions?

To begin with the first problem, psychologists may be close to understanding some of the patterns of preference that infants exhibit. Infants may always tend to look longer at a novel object when given a choice between an object that is novel and one that is familiar, even if they do not always look longest to the most novel of several novel objects. Furthermore, infants may always tend to follow one event, by looking and listening, whenever they are given a choice between a visible object with the same properties as a sound and an object with different properties. Infants may prefer a nonsynchronized object to a synchronized object only when both objects share certain properties with the sound: for example, when both objects are composed of the same rigid substance. If these generalizations are correct, then psychologists should be able to predict the direction of the preferences that infants will exhibit in certain situations.

The second problem raises the question of what it means to ask what infants perceive and know. To some extent, "sensing," "perceiving," and "knowing" are terms with experiential content: They refer to one's conscious awareness of the world. If these terms are understood in this way, then one must conclude that every psychologist is, forever, hopelessly in the dark about the sensations, perceptions, and cognitions of other individuals, young or old. As these terms are used in science and in everyday life, however, their introspective content is rarely in the foreground. We, as ordinary humans and as scientists, will conclude that another person senses, perceives, and knows about aspects of the world whenever this hypothesis leads us to the best, most comprehensive explanation of all the person's actions. This practice, I suggest, should be the practice of psychologists who study infants.

My suggestion echoes the suggestions of several other contributors to this volume. In her discussion of infants' sensory capacities, Teller has recommended that investigators use a variety of methods to probe the same capacities. She suggested, moreover, that experimental findings be evaluated not only against each other but against the findings of experiments from neighboring disciplines. The theory that meshes best with all other scientific theories, and that accords best with all the scientific data, is the theory that sensory psychophysicists should be most ready to accept. In his discussion of infants' capacities to perceive depth and motion, Yonas also suggested that different experiments be undertaken using a variety of stimulus displays and a variety of measures. By seeking "stimulus convergence" and "response convergence" (Yonas & Pick, 1975; see also Bower, 1972) one can come to center on the best account of infants' perceptual capacities.

In sum, the same problem confronts students of infant sensation, perception, and cognition. This problem, moreover, is not specific to studies of human infancy. It is encountered in all branches of psychology, and indeed, all branches of science. The steps necessary to resolve the problem highlight why all scientific experiments need to be tied to scientific theories. When infants' diverse behaviors can be understood in terms of general theories of their mental capacities, we may be more confident that we have begun to understand those behaviors and capacities.

Psychologists now have strong grounds for drawing conclusions about infants' capacities to sense color and spatial pattern and to perceive depth, for a wealth of studies using diverse displays and methods have probed these capacities. The grounds for drawing conclusions about infants' knowledge of objects and events are weaker, because relevant studies of early cognitive capacities are far fewer in number. The burden of this discussion has been to argue, however, that infants' cognitive capacities *can* be studied. As more experiments are conducted, psychologists should come to understand the beginnings of human conceptions about the world and the ways in which those conceptions begin to change. Preferential-looking techniques can contribute to this enterprise.

ACKNOWLEDGMENTS

Preparation of this chapter was supported by a grant from the National Institutes of Health (HD-13428) and by the MIT Center for Cognitive Science under a grant from the A. P. Sloan Foundation's particular program in Cognitive Science. I thank Gilbert Gottlieb and an anonymous reviewer for helpful comments on an earlier version of the chapter.

REFERENCES

Antell, S. E. & Keating, D. P. Perception of numerical invariance in neonates. *Child Development*, 1983, *54*, 695–706.

Bahrick, L. E. *Infants' perception of properties of objects as specified by amodal information in auditory-visual events.* Unpublished doctoral dissertation, Cornell University, 1980.

Bahrick, L. E., Walker, A. S., & Neisser, U. Selective looking by infants. *Cognitive Psychology*, 1981, *13*, 377–390.

Bahrick, L. E. & Watson, J. S. *Contingency perception as a basis for early self perception.* Paper presented at the meeting of the Society for Research in Child Development, Detroit, April, 1983.

Baillargeon, R. *Object permanence in the five-month-old infant.* Paper presented at the meeting of the International Conference on Infant Studies, Austin, Texas, March, 1982.

Ball, W. A. *The perception of causality in the infant.* Paper presented at the meeting of the Society for Research in Child Development, Philadelphia, March, 1973.

Barrera, M. E. & Maurer, D. Recognition of mother's photographed face by the three-month-old infant. *Child Development*, 1981, *52*, 714–716.

Bassili, J. Emotion recognition: The role of facial movement and the relative importance of upper and lower areas of the face. *Journal of Personality and Social Psychology*, 1979, *37*, 2049–2058.

Bertenthal, B. I., Campos, J. J., & Haith, M. M. Development of visual organization: Perception of subjective contours. *Child Development*, 1980, *51*, 1072–1080.

Bertenthal, B. I. & Proffitt, D. R. *Development of infant sensitivity to biomechanical motion.* Paper presented at the meeting of the International Conference on Infant Studies, Austin, Texas, March, 1982.

Bower, T. G. R. Object perception in infancy. *Perception*, 1972, *1*, 15–30.

Bresson, F. & de Schonen, S. A propos de la construction de l'espace et de l'objet: La prise d'un objet sur un support. *Bulletin de Psychologie*, 1976–1977, *30*, 3–9.

Carey, S. The development of face perception. In G. Davies (ed.), *Perceiving and remembering faces.* London: Academic Press, 1983.

Caron, A. J., Caron, R. F., Caldwell, R. C., & Weiss, S. T. Infant perception of the structural properties of the face. *Developmental Psychology*, 1973, *9*, 385–399.

Cohen, S. Developmental differences in infants' attentional responses to face-voice incongruity of mother and stranger. *Child Development*, 1974, *45*, 1155–1158.

DeCasper, A. J. & Fifer, W. P. Of human bonding: Newborns prefer their mothers' voices. *Science*, 1980, *208*, 1174–1176.

Dodd, B. Lip reading in infants: Attention to speech presented in- and out-of-synchrony. *Cognitive Psychology*, 1979, *11*, 478–484.

Fantz, R. L. The origins of form perception. *Scientific American*, 1961, *204*, (May), 66–72.

Fantz, R. L., Fagan, J. F., & Miranda, S. B. Early visual selectivity as a function of pattern variables, previous exposure, age from birth and conception, and expected cognitive deficit. In L. B. Cohen & P. Salapatek (eds.), *Infant perception: From sensation to cognition.* Vol. 1. New York: Academic Press, 1975.

Fox, R. & McDaniel, C. Perception of biological motion in human infants. Science, 1982, *218*, 486–487.

Gibson, E. J. *Principles of perceptual learning and development.* New York: Appleton Century Crofts, 1969.

Gibson, E. J. & Spelke, E. S. The development of perception. In J. H. Flavell and E. M. Markman (eds.), *Cognitive development.* Volume 3 of P. Mussen (ed.), *Handbook of child psychology.* New York: Wiley, 1983.

Gibson, E. J. & Walk, R. D. The "visual cliff." *Scientific American*, 1960, *202* (April), 64–71.

Gibson, E. J. & Walker, A. S. *Intermodal perception of substance.* Paper presented at the meeting of the International Conference on Infant Studies, Austin, Texas, March, 1982.

Gibson, J. J. Comment on "The relation between audition and vision in the human newborn," *Monographs of the Society for Research in Child Development*, 1976, *41* (4, Serial No. 167).

Gottfried, A. W., Rose, S. A., & Bridger, W. H. Crossmodal transfer in human infants. *Child Development*, 1977, *48*, 118-123.

Haith, M. M., Bergman, T., & Moore, M. J. Eye contact and face scanning in early infancy. *Science*, 1977, *198*, 853-855.

Harris, P. Cognition in infancy. In M. M. Haith (ed.), *Infancy and biological development*. Volume 2 of P. Mussen (ed.), *Handbook of child psychology*. New York: Wiley, 1983.

Humphrey, K. & Tees, R. C. Auditory-visual coordination in infancy: Some limitations of the preference methodology. *Bulletin of the Psychonomic Society*, 1980, *16*, 213-216.

Jenkins, H. M. & Ward, W. C. Judgment of contingency between response and outcomes. *Psychological Monographs*, 1965, *79*, 1-17.

Johansson, G. Visual event perception. In R. Held, H. W. Leibowitz, & H.-L. Teuber (eds.), *Handbook of sensory physiology: Perception*. Berlin: Springer-Verlag, 1978.

Kagan, J. *Change and continuity in infancy.* New York: Wiley, 1971.

Kagan, J., Linn, S., Mount, R., & Reznick, J. S. Asymmetry of inference in the dishabituation paradigm. *Canadian Journal of Psychology*, 1979, *33*, 288-305.

Kaufman-Hayoz, R. & Jager, B. *Infants' perception of a face revealed through motion.* Paper presented at the meeting of the Society for Research in Child Development, Detroit, Michigan, April, 1983.

Kellman, P. J. & Spelke, E. S. Perception of partly occluded objects in infancy. *Cognitive Psychology*, 1983, *15*, 483-524.

Kuhl, P. & Meltzoff, A. N. The bimodal perception of speech in infancy. *Science*, 1982, *218*, 1138-1140.

Lamb, M. E. & Campos, J. J. *Development in infancy.* New York: Random House, 1982.

Lawson, K. R. Spatial and temporal congruity and auditory-visual integration in infants. *Developmental Psychology*, 1980, *16*, 185-192.

Leslie, A. M. The perception of causality in infants. *Perception*, 1982, *11*, 173-186.

Lyons-Ruth, K. Bimodal perception in infancy: Responses to auditory-visual incongruity. *Child Development*, 1977, *48*, 820-827.

MacKain, K., Studdert-Kennedy, M., Spieker, S., & Stern, D. Infant intermodal speech perception is a left-hemisphere function. *Science*, 1983, *219*, 1347-1349.

McCall, R. B., Kennedy, C. B., & Applebaum, M. I. Magnitude of discrepancy in the distribution of attention in infants. *Child Development*, 1977, *48*, 772-785.

McDaniel, C. & Odom, R. D. *Preferences for expressive patterns of movement in infancy.* Paper presented at the meeting of the Society for Research in Child Development, Detroit, Michigan, April, 1983.

Meltzoff, A. N. & Borton, R. W. Intermodal matching by human neonates. *Nature*, 1979, *282*, 403-404.

Michotte, A. *The perception of causality.* (T. R. Miles and E. Miles, trans.). London: Methuen, 1963.

Muir, D. & Field, J. Newborn infants orient to sounds. *Child Development*, 1978, *50*, 431-436.

Neisser, U. & Becklen, R. Selective looking: Attending to visually specified events. *Cognitive Psychology*, 1975, *7*, 480-494.

Piaget, J. *The origins of intelligence in children.* New York: International Universities Press, 1952.

Piaget, J. *The construction of reality in the child.* New York: Basic Books, 1954.

Pick, A. D. *Perceiving melodies.* Paper presented at the meeting of the International Society for the Study of Behavioral Development, Munich, August, 1983.

Prather, P. & Spelke, E. S. *Three-month-old infants' perception of adjacent and partly occluded objects.* Paper presented at the meeting of the International Conference on Infant Studies, Austin, Texas, March, 1982.

Reisberg, D. Visual cues and auditory attention. *Acta Psychologica*, 1978, *42*, 331-341.

Ruff, H. A. & Kohler, C. Tactual visual transfer in 6-month-old infants. *Infant Behavior and Development*, 1978, *1*, 259-264.

Schmidt, H. & Spelke, E. S. Gestalt relations and object perception in infancy. Paper presented at the meeting of the International Conference on Infant Studies, New York, April, 1984.

Schwartz, K. *Perceptual knowledge of the human face in infancy.* Paper presented at the meeting of the Society for Research in Child Development, Detroit, April, 1983.

Spelke, E. S. Infants' intermodal perception of events. *Cognitive Psychology*, 1976, *8*, 553-560.

Spelke, E. S. Perceiving bimodally specified events in infancy. *Developmental Psychology*, 1979, *15*, 626-636.

Spelke, E. S. The infants' acquisition of knowledge of bimodally specified events. *Journal of Experimental Child Psychology*, 1981, *31*, 279-299.

Spelke, E. S. *Cognition in infancy.* Occasional paper #23, MIT Center for Cognitive Science, 1983.

Spelke, E. S., Born, W. S., & Chu, F. Perception of moving, sounding objects in infancy. *Perception*, 1983, *12*, 719-732.

Spelke, E. S. & Cortelyou, A. Perceptual aspects of social knowing: Looking and listening in infancy. In M. E. Lamb and L. R. Sherrod (eds.), *Infant social cognition.* Hillsdale, NJ: Erlbaum, 1981.

Spelke, E. S. & Owsley, C. J. Intermodal exploration and perceptual knowledge in infancy. *Infant Behavior and Development*, 1979, *2*, 13-28.

Starkey, D. P. & Cooper, R. G. Perception of numbers by human infants. *Science*, 1980, *210*, 103-1034.

Starkey, D. P., Spelke, E. S., & Gelman, R. *Number competence in infants: Sensitivity to numeric invariance and numeric change.* Paper presented at the International Conference on Infant Studies, New Haven, CT, April, 1980.

Starkey, D. P. Spelke, E. S., & Gelman, R. Detection of intermodal numerical correspondences by human infants. *Science*, 1983, *222*, 179-181.

Strauss, M. S. & Curtis, L. E. Infant perception of numerosity. *Child Development*, 1981, *52*, 1146-1152.

Tighe, E. & Leaton, R. *Habituation.* New York: Academic Press, 1976.

von Hofsten, C. Eye-hand coordination in newborns. *Developmental Psychology*, 1982, *18*, 450-461.

Wagner, S., Winner, E., Cicchetti, D., & Gardner, H. "Metaphorical" mapping in human infants. *Child Development*, 1981, *52*, 728-731.

Walker, A. S. Intermodal perception of expressive behaviors by human infants. *Journal of Experimental Child Psychology*, 1982, *33*, 514-535.

Welch, R. B. & Warren, D. H. Immediate perceptual response to intersensory discrepancy. *Psychological Bulletin*, 1980, *88*, 638-667.

Wertheimer, M. Psychomotor coordination of auditory and visual space at birth. *Science*, 1961, *134*, 1692.

Wishart, J. *The development of the object concept in infancy.* Unpublished doctoral dissertation, University of Edinburgh, 1979.

Yonas, A. N. & Pick, H. L., Jr. Studies of spatial perception in infancy. In L. B. Cohen & P. Salapatek (eds.), *Infant perception: From sensation to cognition.* New York: Academic Press, 1975.

from L12