tinuum, rather than dichotomous categories. For discussions of automaticity and its characteristics, see Bargh (1989, 1996).

3. It should be noted that there may be important differences in how people explain social and nonsocial events. For example, the actions of people may be produced and guided by internal motivations, but such internal explanations are typically not invoked for the actions of baseballs, electrons, or hurricanes. For a relevant discussion, see Ostrom (1984).

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Young Infants' Perception of Object Unity: Implications for Development of Attentional and Cognitive Skills

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When we look at the world around us, we do not experience the surroundings as an unorganized patchwork of colors and shapes, but rather as occupied by segregated objects, each characterized by individual boundaries and surfaces. The fact that objects often occlude one another and commonly go in and out of sight seems to pose us little difficulty. We assume that most objects are continuous over space and time, that they do not generally disappear and reappear, and that one object does not necessarily end at another's boundary. This subjective experience is due to our facility at using the wide variety of visual cues available to us, as well as commonsense notions of object permanence.

How is it that even though infants are born with no visual experience, they are, after some span of time, able to visually parse the optic array into segregated objects? Some theories addressing this question have stressed innate core principles that specify the fundamental object properties such as object identity and spatiotemporal continuity (Spelke, 1990). Others have proposed that a protracted period of experience in observing and manipulating objects is necessary for development of these skills (Piaget, 1936/1952, 1937/1954). The studies reported here suggest that both of these views are incorrect. There is little evidence that in-

Recommended Reading

Kellman, P.J. (1993). Kinematic [illegible]dations of infant visual [illegible]tion. In C.E. Granrud (Ed.), [illegible] *perception and cognition in* [illegible] (pp. 121–173). Hillsdale, N[illegible]baum.

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fants are born equipped with sophisticated object perception abilities (contrary to theories invoking innate core principles), but there is rapid progress in perception of object boundaries, depth, and occlusion (arguing against the necessity of extended experience with objects). By the middle of the 1st year of life, infants seem to view objects in their surroundings in much the same way as do adults, by exploiting a variety of the visual cues available to them in the optic array.

USING VISUAL INFORMATION TO PARSE THE OPTIC ARRAY

Consider the problem that confronts a person who examines a scene visually. When a scene is viewed from a stationary vantage point, the accuracy of the perception of the relative distances of objects can be ascertained by attending to one or more of a variety of depth cues or to sources of information for the segregation of disparate surfaces in the visual array. These cues include linear perspective, relative and familiar size, height in the visual field, texture gradients, shading, shadows, and points of occlusion known as T-junctions, where the edge of a far surface is occluded by a near surface (Gibson, 1950). In addition, a person's two eyes pick up slightly different views of many objects, and most adults are able to use this binocular disparity as a cue to the distance of objects. Also, the lenses of the eyes accommodate appropriately via the ciliary muscles, and eye position converges and diverges as necessary, to focus on near and far objects. Finally, motion adds important information about depth. A person moving through the environment perceives retinal images of near objects to move past more quickly than images of far objects. This motion parallax is a cue to the relative distance of objects. Furthermore, the motion of objects viewed against a stationary background aids in segregation because the background is progressively occluded (deleted) and unoccluded (accreted) by the moving objects. These various cues are generally redundant in everyday experience, in that they are consistent in the information they provide about object distance, although there is variation in their individual reliability (Cutting & Vishton, 1995).

Young infants are confronted with the same optic array as are adults (although there may be limitations in visual acuity in very young infants). How do they respond to such a seemingly bewildering variety of visual cues? For that matter, how can we know what cues are used by young (prelingual) infants to parse the optic array? Is there a hierarchy of cues, such that one or more cues are used early, whereas the use of others awaits some period of development?

INFANTS' PARSING OF THE OPTIC ARRAY: THE OBJECT UNITY TASK

One way in which these questions have been addressed is with displays depicting partly occluded subjects (Kellman & Spelke, 1983). For example, the display in Figure 1a depicts two rod parts, moving back and forth, above and below a box. When adults view such a display, they typically assume the unity of the rod parts, perhaps in part because the visible rod parts are aligned and undergo common motion above and below the box.

To investigate infants' perception of object unity in this display, researchers use what is called a *habituation* procedure. The first step is to present the display to each infant repeatedly and determine the number of repetitions following which the infant's looking times become progressively shorter. This habituation is thought to reflect a decrement of interest on the infant's part. The next step is to follow habituation immediately with the presentation of a different (test) display. If the infant recovers interest immediately (i.e., looks longer at the display), the researcher concludes that the infant has noted the difference. However, if the infant's looking times continue to be short, the researcher concludes that either the infant does not note any difference between the habituation and test stimuli or the test stimulus is not sufficiently novel to elicit recovery. In the case of the rod-and-box display, preference for a broken rod, or two disjoint rod parts (Fig. 1c), over a complete rod (Fig. 1b) after habituation is taken to indicate that the infant perceived the two rod parts in the habituation display as belonging to a single, partly occluded object. That is, the complete rod is familiar; the broken rod, relatively novel. (A control rod-and-box display is also used, to assess whether there is an inherent preference for either test display. Typically, a control display contains two rod parts and a box, but only the top rod part moves while the bottom part remains stationary. All the studies reported here have employed such a control condition, and have found no consistent preference for either test display in any case.)

In summary, then, the logic used in interpreting infants' reactions to the stimuli used in the rod-and-box displays is as follows. An infant is habituated by presenting a sequence of rod-and-box displays until looking time declines. If, after habituation, the infant looks longer at the broken rod than at the com-

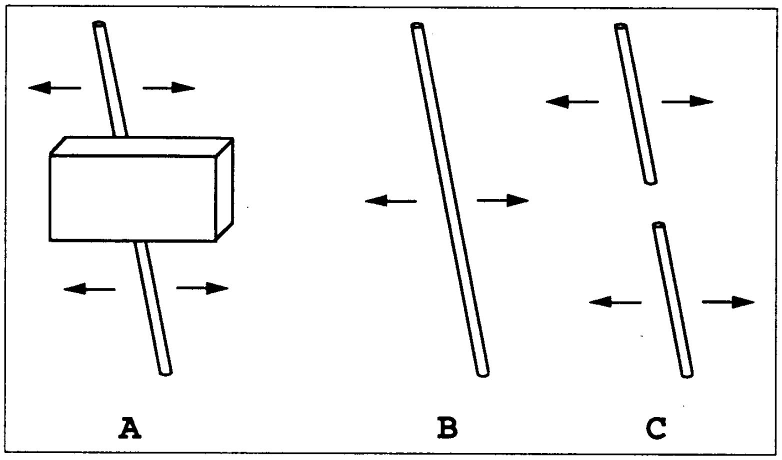

Fig. 1. The rod-and-box procedure (after Kellman & Spelke, 1983). Individual infants are presented with the display shown in (a) until they habituate (i.e., the time they look at the display is less than half the original level, averaged over trials). Following habituation, infants are presented with complete-rod (b) and broken-rod (c) test displays, either on alternating trials or side by side.

plete rod, it is assumed that the rod parts in the habituation stimulus were perceived as a complete, partly occluded rod. In contrast, if the infant looks longer at the complete rod, the rod parts in the habituation stimulus are assumed to have been perceived as disjoint objects. If there is no preference for either test display, it is assumed that the infant's perception of object unity may have been ambiguous. The experimenter manipulates visual cues in the habituation stimulus to determine the cues affecting the way in which infants parse the visual display into segregated objects.

HOW DO YOUNG INFANTS PERCEIVE OBJECT UNITY?

Early studies of the cues that support perception of object unity (Kellman & Spelke, 1983; Kellman, Spelke, & Short, 1986) concluded that common motion of the rod parts, relative to a stationary box and background, was the primary visual cue used by infants in determining that the rod parts belong to a unified object. This claim was based on the fact that infants who were 4 months of age preferred the broken rod over the complete rod after viewing displays in which both rod parts moved (either horizontally, vertically, or in depth) behind a stationary box. In contrast, these infants showed no preference for either test display after viewing habituation displays in which a box moved in front of a stationary rod, or both rod and box moved together, or there was no motion.

More recent studies also using rod-and-box displays have begun to call into question the notion that common motion uniquely supports young infants' perception of object unity. Note that if only common motion supports perception of object unity in young infants, then habituation to displays in which this cue is available should result in consistent posthabituation preference for the broken rod.

My colleagues and I began our investigations in this area by asking if three-dimensional depth cues are necessary to support young infants' perception of object unity (Johnson & Náñez, 1995). We presented two-dimensional (computer-generated) rod-and-box displays against a textured background to 4-month-olds until habituation (see Fig. 2a). Test displays of broken and complete rods followed in alternation. The rods and rod parts in the test displays moved back and forth in an identical manner. The infants consistently preferred the broken rod, suggesting that whatever cues remained in the display were sufficient to support 4-month-olds' perception of object unity.

We next asked if accretion and deletion (i.e., progressive uncovering and covering) of background texture contributes to young infants' perception of object unity, perhaps as a supplementary depth cue (Johnson & Aslin, 1996). For this investigation, we used two-dimensional rod-and-box displays identical to those in the study just described but for a matte black background (no texture) (Fig. 2b). Four-month-olds showed no consistent preference for either test display. This result may seem somewhat counterintuitive, in that it is not immediately obvious how accretion and deletion of texture on the far surface (the background) contributes to determining if the rod parts are connected behind the near surface (the box).

We interpreted this result by appealing to an account of adults' perception of the connectedness of edges behind an occluder. Nakayama and his colleagues (Nakayama & Shimojo, 1990; Nakayama, Shimojo, & Silverman, 1989) noted that in order to segregate objects appropriately in an occlusion display, the viewer must determine in which depth plane each surface resides (*depth placement*), as well as discern the outer contours of each surface (*contour ownership*), realizing that the contours of some objects may be partly occluded. For example, in a rod-

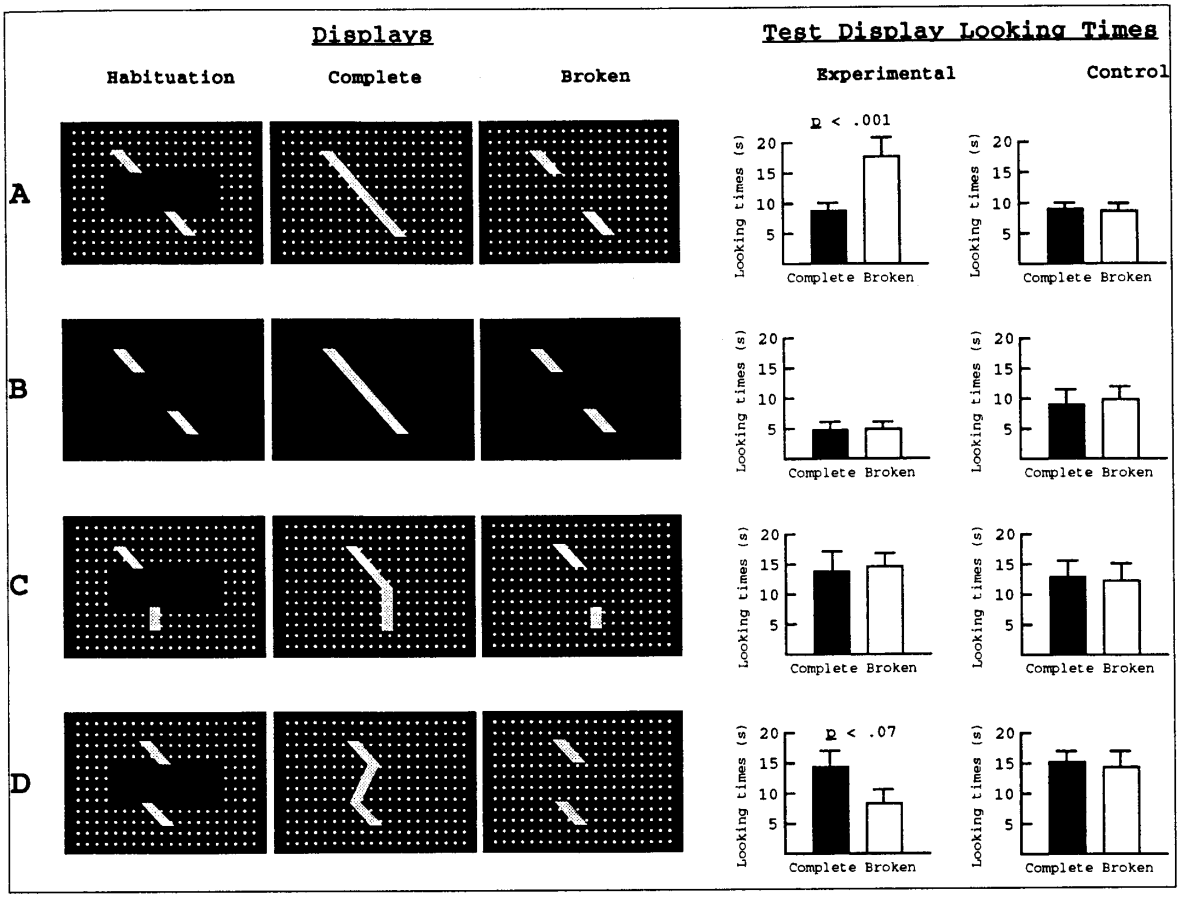

Fig. 2. Habituation and test displays, and looking times to test displays in experimental and control conditions, from studies of 4-month-olds' perception of object unity. In the experimental displays, the rod parts moved back and forth together, and the box was stationary. In the control displays, only the top rod part moved while the bottom remained stationary. All displays were two-dimensional and computer-generated. The preferred test display is inferred to be novel relative to the habituation display. Displays and looking times are shown for rod-and-box displays with background texture and aligned rod edges (a), with no background texture and aligned rod edges (b), with background texture and nonaligned but relatable rod edges (c), and with background texture and nonaligned and nonrelatable rod edges (d).

and-box display, the viewer must perceive that the box is closer than the rod and that the rod's boundary does not end at the top and bottom edges of the box. If either process is disrupted, then perception of the rod parts' unity may not occur. In the present study, it appears that the infants may not have appropriately perceived the depth relations in the display. Interestingly, 4-month-olds have been found to perceive unity in three-dimensional displays without background texture (Slater et al., 1990). Thus, these infants used other cues (such as binocular disparity) to determine depth placement of the display elements.

Our next study explored the role of the alignment of rod edges in perception of object unity (Johnson & Aslin, 1996). We devised two displays in which the rod edges were nonaligned; the rod parts moved back and forth against a textured background. In one display (Fig. 2c), the edges were oriented such that they were relatable (i.e., they would meet if extended behind the box, as in Fig. 3b; see Kellman & Shipley, 1991, for a formal definition of relatability). In the other display (Fig. 2d), the edges were nonrelatable (see Fig. 3c). The infants appeared to strongly rely on relatability as information for edge connectedness. When the rod edges were nonaligned but relatable, the pattern of posthabituation preference indicated ambiguity regarding their unity. However, when the rod edges were nonaligned and nonrelatable, the infants seemed to perceive the rod

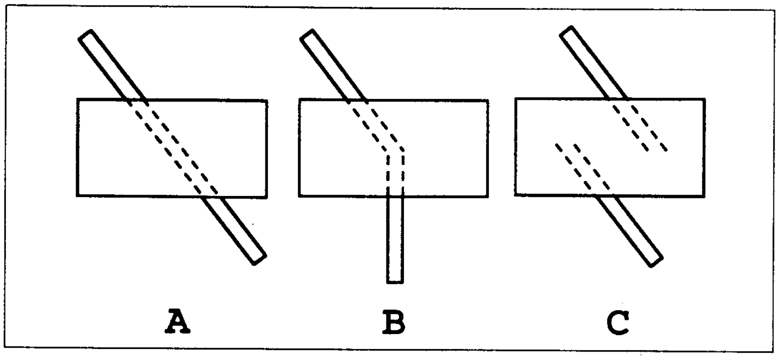

Fig. 3. Rod-and-box arrangements demonstrating alignment and relatability. Edges are defined as relatable if they would meet at an obtuse angle if extended behind an occluder (see Kellman & Shipley, 1991, for details). In (a), the two rod parts are aligned. Additionally, they are relatable: The edges of the two rod parts would meet if extended behind the box (indicated by the dotted lines). In (b), the two rod parts are not aligned, but they are relatable. In (c), the rod parts are neither aligned nor relatable.

parts as disjoint, despite the common motion. Again, this result is consistent with a two-process account of perception of object unity, involving both depth placement and contour ownership. The previous study showed how disruption of depth placement interferes with perception of object unity. The results from the nonaligned-edge conditions in this study suggest that contour ownership also plays an important role in this process.

ACCOUNTING FOR DIFFERENCES IN PERCEPTION OF OBJECT UNITY IN VARIOUS DISPLAYS: THE THRESHOLD MODEL

How is it possible to reconcile the results from the earlier and later studies, which seem to disclose such different roles of individual visual cues in infants' perception of object unity? There does not seem to be a single cue, such as common motion, central to this process. Rather, perception of object unity appears to be determined by a variety of cues. Aslin and I (Johnson & Aslin, 1996) have proposed a *threshold model*, stipulating that perception of object unity occurs in infants when *sufficiency* of visual information meets *efficiency* of perceptual skills, cognitive skills, or both. That is, there must be an adequate number of cues available in an occlusion display, and infants must be sensitive to them, in order for object segregation to occur. Four-month-olds' perception of object unity in some displays but not others indicates that infants at this age are differentially sensitive to available cues. By adding or deleting individual cues in habituation displays, researchers can learn which cues a particular age group uses.

The threshold model is more descriptive than explanatory. It is not yet possible to predict from the model whether a particular set of cues in a given occlusion display will support perception of object unity for infants at a given age. However, the model is consistent with what is currently known about infants' parsing of the optic array, and we hope that further research will provide a more thorough outline of the development of cue use in infants.

The model is also consistent with recent theories of human visual perception that characterize the visual system as utilitarian (Ramachandran, 1988). That is, the visual system is designed to take advantage of whatever information is available at the time: Perception is akin to a "bag of tricks" that are used because they work, across real-world situations, well enough to be reasonably reliable. The often-cited apparent sophistication of infants' perceptual and cognitive skills (e.g., Baillargeon, 1993) may be partly due to the redundancy of the cues available in most situations. When cues are examined systematically, it does not seem surprising that perceptual skills are taxed, because redundancy is controlled.

THE EMERGENCE OF PERCEPTION OF OBJECT UNITY

Thus far, I have restricted the discussion to 4-month-olds. Does perception of object unity at this young age imply contributions of innate principles underlying object perception (e.g., Spelke, 1990)? If so, one might expect newborn infants to perceive object unity in occlusion displays. However, newborns have been found to consistently prefer a complete rod to a broken rod after habituation to a rod-and-box display (Slater et al., 1990). This response pattern is the opposite of the one reported in 4-month-olds, and suggests that some period of development is necessary for perception of object unity to emerge in infants.

Recently, Náñez and I investigated the emergence of perception of object unity by showing rod-and-box displays to 2-month-old infants, asking whether their responses would be more similar to those of 4-month-olds or newborn infants (Johnson & Náñez, 1995). Interestingly, the 2-month-olds responded like neither of these age groups, instead showing an approximately equal preference for the two test displays (Fig. 4a). This finding might be interpreted to indicate that 2-month-olds are not fully capable of perceiving object unity, but recall the threshold model—it might be that with additional visual information, infants at this young age would be more likely to perceive the unity of the rod parts.

This hypothesis was tested in three ways, all of which involved simply showing more of the rod behind occluders that were reduced in size (Johnson & Aslin, 1995). In one display, the box was made smaller in height; in a second display, a vertical gap was placed in the box; and in a third display, the box contained two gaps displaced horizontally (Figs. 4b, 4c, and 4d, respectively). Each display permitted more of the rod to be seen as it moved back and forth behind the box. In all three conditions, 2-month-olds showed preferences for the broken rod, indicating early perception of object unity. These results support the threshold model. That is, it seems likely that the threshold for the level of visual information required for 2-month-olds' perception of object unity is higher than the threshold of 4-month-olds. When this requirement is met in displays that are richer in cues, the younger infants respond to unity.

What about even younger infants? Is it possible that the displays used previously to assess newborns' perception of object unity (i.e., Slater et al., 1990) were not sufficiently rich in cues to meet what might be expected to be a very high threshold? This question was recently addressed by showing newborns full-cue rod-and-box

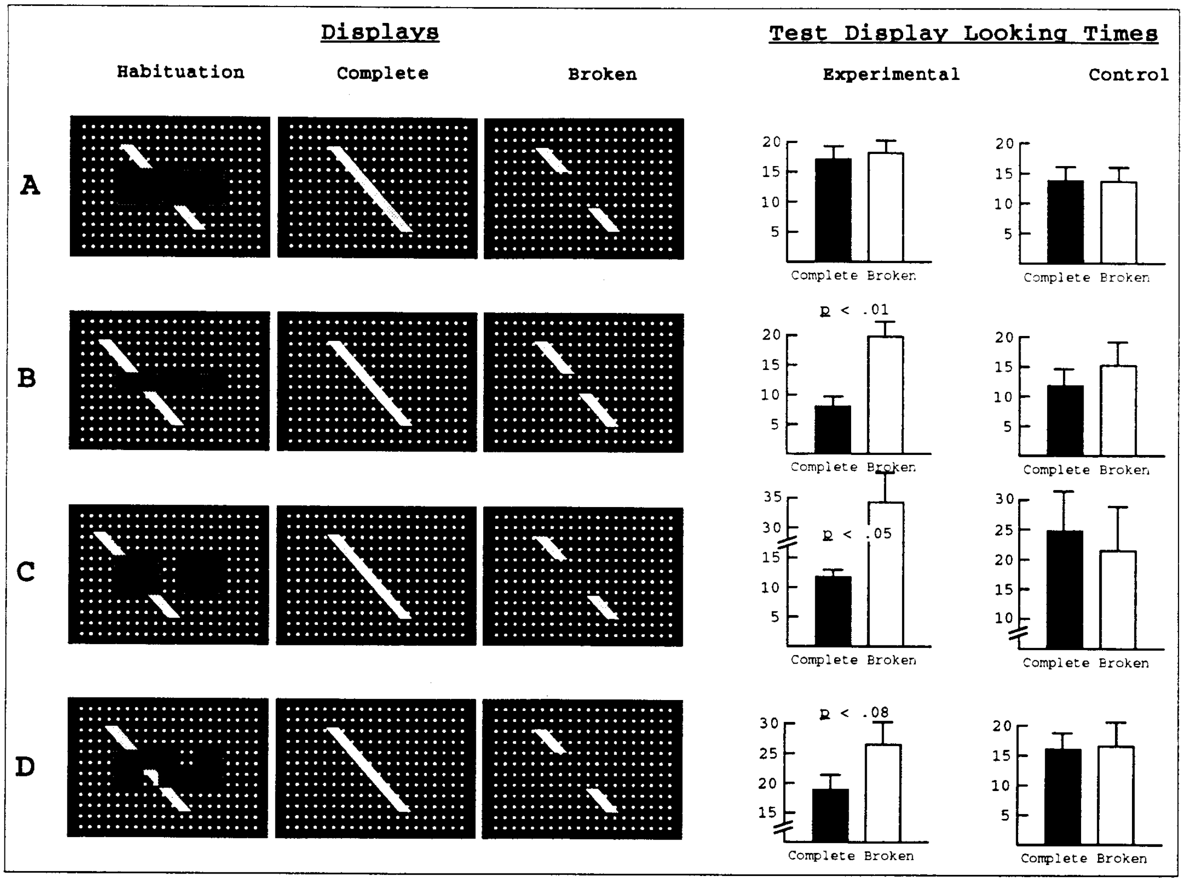

Fig. 4. Habituation and test displays, and looking times to test displays in experimental and control conditions, from studies of 2-month-olds' perception of object unity. Again, all displays were two-dimensional and computer-generated. Displays and looking times are shown for rod-and-box displays with background texture and aligned rod edges (a), with small boxes (b), with boxes having a single gap (c), and with boxes having a double gap (d). The displays in (a) are identical to those shown to 4-month-olds (Fig. 1a). In the single-gap and double-gap control conditions, the rod was not visible at any time in the gap.

displays, rich in visual information in support of object unity (Slater, Johnson, Brown, & Badenoch, 1996). Specifically, the cues included common motion of the rod parts relative to a stationary box and background, color differences between surfaces (known to be discriminable by newborns), reduced size of the occluder, a large difference in depth between rod and box, and alignment of rod edges. However, even after habituation to the rich-cue display, the newborns showed a reliable preference for the complete rod. Thus, there is little evidence to suggest that they took advantage of the extra visual information available to perceive unity.

It may be that newborns lack not the perceptual skills, but rather the cognitive skills necessary to infer the hidden region of the rod. Although one might argue that cognitive skills are not involved in this task (if one takes object unity to be an object property that is available directly, much as shape, color, and depth are), I would argue that cognitive skills are in fact involved because the viewer must take account of an object part that cannot be seen directly. Indeed, the responses of newborns described here and elsewhere (Slater et al., 1990) are most consistent with newborns' perception of the separated rod surfaces as disjoint objects.

CONCLUDING REMARKS

The most interesting questions remaining involve how it is that infants develop perception of bounded, segregated, continuous objects after only a few months of visual experience. The studies of perception of object unity described in this review clarify many aspects of young infants' object perception skills, but the mechanisms underlying emergence of these fundamental abilities remain unknown. At this point, the data suggest that the visual system is opportunistic in its development, taking advantage of whatever information is available at the time. No doubt some mechanisms of development consist of rapid improvements in infants' attention to, and interpretation of, visual cues they encounter in their daily activities.

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Note

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