CHAPTER SEVEN

Object perception and object knowledge in young infants: A view from studies of visual development

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INTRODUCTION: OBJECT PERCEPTION AND OBJECT KNOWLEDGE IN EVERYDAY LIFE

Imagine you are sitting at a desk whose top is cluttered with various objects, such as papers, books, a computer and keyboard, and other such items. Among the clutter you spy two long, thin, yellow surfaces, whose edges are aligned, protruding from beneath a piece of paper. Without much difficulty, you are able to interpret these surfaces as belonging to a single object, in this case a partly occluded pencil. Not only can you perceive this object, but you know quite a bit about it. For example, you know that one end can be used to produce marks on paper – writing, drawing, and the like. You know what the pencil is composed of, and you might recall where you obtained the pencil.

But there is much more that you know, including general object knowledge that is not limited to this pencil. For example, you know that if you were to pick up the pencil and drop it, it would fall to the nearest surface below. You know that if you were to toss the pencil towards the bin, it might land in or near the bin, and would follow a predictable trajectory on the way to its resting place. You know that if you were to cover the pencil completely with the paper, the pencil would still be there, in the place you left it, were you to later search for it. You know that it is a solid object, and could not pass through the space occupied by another object.
Consider thus the extent of your knowledge of this pencil. Not only do you know about this particular item, with which you have had some experience, but you hold similar beliefs about almost every object you see every day, and countless other objects you have seen, will see in the future, or can imagine. Your everyday existence as you know it would scarcely be possible without this knowledge, because without it, the world and the results of your actions in the world would not be predictable.

Complete object knowledge comprises several supporting skills, some perceptual, some cognitive, and others rather more difficult to categorise. Perceptual skills include visual acuity (the ability to resolve detail), and the ability to distinguish the boundaries, colours, luminance levels, and textures of surrounding surfaces. Depth perception is necessary to discriminate surfaces against the background. The ability to track moving objects in the environment is important as well, because motion often is an important cue for segregation of visible surfaces. All of these skills rely on efficient visual scanning, the ability to foveate objects of interest (i.e. to focus the object's image on the fovea, the centre of the retina at the back of the eye, where visual acuity is generally highest).

Cognitive skills are also required for complete object knowledge, such as knowledge of objects' physical properties: unity, location, size, inertia, continuity across time and space, cohesion, gravity, and support, among others. For example, it is often necessary to "fill in" partly occluded portions of objects. This involves extension of the visible edges behind the occluder across a discontinuity in surface boundaries. An object's location and size must be recalled in order to recognise it as the same object on later encounters. The ability to keep in mind that an object maintains a lawful trajectory while moving, even when the trajectory is unseen, contributes to this recognition as well. Knowledge of cohesion underlies understanding solidity and the fact that an object cannot pass through the space occupied by another object.

Other skills seem both perceptual and cognitive, such as the object constancies: an object is recognised even though it is seen from a variety of angles (shape constancy), and from a variety of distances (size constancy). For example, the cover of a book would appear perfectly rectangular only if seen straight on — more often, its retinal image is that of a trapezium. The trapezium may be seen in a variety of shapes and sizes, but the "meaning" remains invariant: the cover of the book. Finally, object identity (or identity constancy) is the recognition that the object does not change into a new object when it moves, becomes temporarily occluded, or is encountered again after looking away. Object identity also dictates that an object moves to another location only on a continuous path — if an object similar in appearance turns up elsewhere in the visual array, it must be a distinct object. Clearly, many skills are involved in the simple act of recognising your pencil, and these skills are used countless times in your daily activities.

THE DEVELOPMENT OF OBJECT KNOWLEDGE: PIAGET'S THEORY

How did you come to this state of knowledge about the world and the objects in it? Did you learn about objects when you were a young infant, by handling, examining, and manipulating them? Alternatively, does most object knowledge come from being taught, via language? Or is object knowledge accessible simply by looking — are object properties perceived directly, without cognitive input? Or is object knowledge present at birth, as part of our genetic endowment?

If you have spent much time around young infants older than 5 or 6 months (when coordinated reaching for objects emerges in most infants), you might conclude that the first of these possibilities provides the best account of the development of object knowledge. After infants develop reaching and grasping skills, they often grab any small object they can, visually inspect it, bang it on the nearest hard surface, shake it, put it in their mouth, drop it, and so on. These are excellent ways of exploring object properties.

Infants' use of manual skills to learn about objects was the focus of the first comprehensive theory to address the question of development of object knowledge, that of Jean Piaget (1952; 1954). Piaget was a keen observer of infants and children (including his own), meticulously recording their responses to everyday situations and tasks he devised. Although Piaget wrote extensively about many aspects of development, I will discuss here only a small part of his theory, concerning object permanence, or the object concept. According to Piaget (1954), object permanence encompasses the knowledge that objects continue to exist, and that they maintain their physical and spatial properties, when no longer in sight or manual contact. On the basis of infants' responses to hiding tasks, he outlined a progression of stages through which infants pass on their way to full object permanence.

In stages 1 and 2 (birth to about 4 months), infants who watch as an interesting object is covered act as if the occluded object no longer exists: they show no surprise at the object's disappearance, nor do they attempt to look for the object. In stage 3 (about 4 to 8 months), infants will retrieve an object from behind an occluder if they are in current manual contact, but will not search otherwise. In stage 4 (about 8 to 12 months), infants will search under an occluder, even without manual contact on occlusion. Thus they demonstrate knowledge that the occluded object still exists.
However, this does not yet constitute object permanence, for infants at stage 4 often make a very interesting search error when confronted with two occluders. If an object is repeatedly hidden at one location (location A), the infant is allowed to search and retrieve the object, and then the object is hidden at a second location (location B) as the infant watches, he or she will often direct the search to A again! This outcome seems surprising – after all, the infant watched as the object was being hidden at B – why would he or she then search at A? Piaget (1954) accounts for this “A-not-B” error (also called the stage 4 error) by arguing that stage 4 infants do not maintain an objective mental representation of the object. Rather, for the infant, reaching at a particular location results in an interesting outcome (the desired object). Thus the object is represented by the infant in terms of his or her actions, not as separate from them. (The A-not-B error has inspired a very large number of studies. For an excellent summary and theoretical account, see Wellman, Cross, & Bartsch, 1987.) By stage 5 (about 12 to 18 months), infants overcome the tendency to search at A incorrectly if they watch the object being hidden at B. However, if the object is transferred invisibly to B, for example in the hider’s hand, stage 5 infants often err in search. By stage 6 (about 18 to 24 months), infants demonstrate full object permanence, because they search all possible locations – thus indicating that they know the object has to be somewhere. This constitutes the advent of representational abilities, which would encompass many of our common-sense notions of the pencil’s properties described above.

For Piaget (1954), then, evidence of infants’ object knowledge was provided by effective search for an object that was hidden and then placed. Even before manual search abilities emerge, however, there is ample evidence (some of which is reviewed later) that infants have already acquired much object knowledge. The viewpoint espoused in this chapter is that visual skills are the foundation for much of humans’ object perception and object knowledge. It is true that search patterns can be informative, as Piaget suggested, but it may be that manual search is not always the best index of an infant’s cognitive abilities (Baillargeon, Graber, DeVos, & Black, 1990). It is also true that other perceptual and cognitive domains contribute in very important ways to our understanding of the world (such as our facility at using language as a communicative tool). However, humans are an inherently visual species, and much information we take in about our environment is visual. Fortunately for those of us interested in the development of object perception and object knowledge, the past three decades have seen tremendous advances in the use of methodologies that exploit infants’ visual preferences. Researchers have obtained a fair measure of what it is that infants at various ages attend to, what they find interesting, what they may or may not be able to distinguish, and the like, and from there infer some of the cognitive activities that must underlie these preferences. Many of these methodologies are described later.

The next part of the chapter will follow a chronological sequence. First I briefly describe fundamental visual skills and their development from birth, and then outline what is currently believed to be the state of object knowledge in different age groups. After this summary of the research, a brief consideration of theoretical viewpoints since Piaget will be presented.

**VISUAL SKILLS IN THE NEONATE: THE FOUNDATIONS OF OBJECT PERCEPTION AND OBJECT KNOWLEDGE**

At first glance (and perhaps even with repeated glances), the neonate, or newborn infant, seems hopelessly disorganised. Sleeping, waking, and feeding may not follow any discernible pattern for months to come. At times, the neonate may seem completely unresponsive to visual or auditory stimuli. He or she may thrash about, or cry, or stare into space for no apparent reason. Young humans require adult care for many months before they are able to perform even simple tasks, such as feeding themselves. In this way, humans are an **alticial** species, as opposed to other species that are better described as **precocial** (for example, hatchling sea turtles receive no care, and on hatching must rush to the ocean and begin life on their own).

There is currently much controversy about whether very young infants’ perceptual and cognitive abilities are also best described as alticial. For example, one view posits that neonates’ visual abilities are limited by lack of cortical functioning (Atkinson, 1984; Johnson, 1990), or more precisely, that there are only “islands” of cortical functioning at birth. (Cortical functioning refers to the cortex, the largest part of the human brain. The cortex is responsible for humans’ reasoning, planning, and linguistic abilities, and many visual skills.) Without full functioning of the cortex, object knowledge obviously would be restricted. However, the results of a variety of studies suggest that neonates do respond to some object properties.

**Neonates’ visual limitations**

Chapter 1 in this volume provides an excellent overview of the development of fundamental visual skills. At the risk of being redundant, a few points bear repeating in the context of the present chapter.

Foveation consists of directing one’s gaze to items of interest in the visual array. Foveation is most readily accomplished in humans via eye
Neonates' visual abilities

After presenting this rather bleak portrait of neonates' perceptual capabilities, I now turn to a variety of studies presenting a contrasting picture. These studies describe organisation of eye movements, memory abilities, visual preferences, and face recognition, all in infants no more than a few days old. Many of the abilities revealed by these studies are difficult to reconcile with the notion that vision is severely compromised in neonates, and these discrepancies remain unresolved. (The debate continues!)

Using corneal reflection, Haith (1980) recorded eye movements of neonates under a variety of conditions, and found that much of their visual behaviour could be captured by the following "rules," or innate tendencies.

Rule 1: If awake and alert and light not too bright, open eyes. Rule 2: If in darkness, maintain a controlled, detailed search. Rule 3: If in light with no form, search for edges by relatively broad, jerky sweeps of the field.

Rule 4: If an edge is found, terminate the broad scan and stay in the vicinity of that edge (Haith, 1980, p. 96). It seems that even though vision may be compromised in neonates, they often seem motivated to look at their surroundings.

Neonates display the capacity for memory (Slater, Morison, & Rose, 1982). If a neonate is repeatedly shown the same stimulus, looking duration typically is high initially but declines after several trials. If a novel stimulus is then presented, looking duration often increases again. This pattern of attention has been interpreted to reflect decrement of interest (habituation) and subsequent recovery of interest (dishabituation). Thus the habituation stimulus is held in memory while viewed repeatedly, and subsequently compared to the novel (test) stimulus. The mismatch between the remembered and novel stimuli leads to renewed interest. This method is widely used to investigate perceptual and cognitive development in infants, including older infants, as we will see. (Care is taken to ensure that posthabituation recovery is not due to inherent biases or preferences. Controls were employed in the studies presented later to address this issue, but will not be discussed.)

Neonates show "natural," or unlearned, visual preferences. That is, neonates seem to prefer some stimuli over others when stimuli are presented side by side. Based on evidence from dozens of studies, Slater (1995) outlined nine specific preferences: patterned over nonpatterned stimuli, curvature over straight edges, moving over stationary stimuli (and certain types of motion are preferred over others), three-dimensional over two-dimensional stimuli, horizontal over vertical gratings, upright over slanting stimuli (when the stimulus slants away from view), high over low contrast, certain sizes over others, and faces over similar, "nonface" stimuli. Attempts have been made to explain these innate preferences.
with a single principle, such as the contrast sensitivity function (Banks & Salapatek, 1981), with some, but not universal, success (see Slater, 1995, for discussion).

One surprising recent finding is the innate preference for faces over other stimuli. Figure 7.1 depicts stimuli that have been shown to neonates (Johnson, Drzirawiec, Ellis, & Morton, 1991). The infants were seated on an experimenter's lap, who held each stimulus at midline about 18–25 cm from the infant's eyes, and then moved it side to side until the infant no longer tracked it. The infants tracked the face-like stimulus farther than any of the others, indicating the ability to discriminate the stimuli, as well as the innate preference for faces.

Neonates have also been found to learn individual faces very rapidly, distinguishing real faces from one another. The most likely candidate for a readily learned face is, of course, the mother, and mother's face is learned within days after birth (Bushnell, Sai, & Mullin, 1989). In this preferential-looking study, 4-day-old neonates consistently looked longer at their mother's face than at a female stranger, who was similar to the mother in terms of hair colour and skin tone. Apparently, this recognition is not dependent solely on facial features. The effect disappears if the women's hairlines are covered with a scarf (Pascali, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995). Thus attention to outer contours seems to contribute to neonates' face recognition abilities.

**OBJECT PERCEPTION AND OBJECT KNOWLEDGE IN THE NEONATE**

We have seen evidence for both limitations and competencies in neonates' visual abilities. My goal in presenting these studies has been to offer the reader some appreciation of the challenges faced by the neonate, who is born not only with no visual experience, but with poor vision with which to try to make sense of the world! Nevertheless, there is clear evidence that some visual skills are present at birth. Do these skills extend to object perception, and perhaps object knowledge?

There have been few studies of object perception and object knowledge with neonates, and these studies provide mixed evidence for such abilities. The question is whether infants experience the visual array as a mosaic of shapes, or as composed of objects that are independent, bounded entities, located at different distances from the observer. To my knowledge, there have been no published studies of neonates' knowledge of objects' physical properties, except perception of object unity, described later.

Neonates have been found to demonstrate both size and shape constancy. In a study of size constancy, Slater, Mattock, and Brown (1990) presented neonates with cubes at different distances using a familiarisation method (similar to habituation, but with a fixed trial duration). Each infant viewed either a small cube or a large cube during familiarisation. Thus each infant was exposed to the same-sized object at different distances. After familiarisation, the infants were shown both cubes side-by-side, the small cube nearer and the large cube farther, so that their retinal images were identically sized (Fig. 7.2). The infants looked longer at the cube they were not familiarised with (consistent with the novelty preferences commonly observed in habituation studies). This indicates that the neonates differentiated the two cube sizes despite the similarities of the retinal sizes, and abstracted the familiar cube's real size over changes in distance.

In a study of shape constancy, Slater and Morison (1985) adopted a similar method. Neonates were presented with a single shape during familiarisation, either a trapezium or a square, shown at a different slant during each trial. Each infant thus viewed the same shape in different orientations. After familiarisation, the infants saw both stimuli side-by-side, the novel stimulus in the frontal plane, and the familiar stimulus in a new orientation. The infants looked longer at the stimulus they had not seen during familiarisation, indicating that they abstracted the real shape of the stimulus seen during familiarisation as it was rotated in three dimensions.

Studies of identity constancy have yielded less straightforward results. Perhaps because identity constancy itself incorporates several aspects of object knowledge. Slater, Morison, Town, and Rose (1985) habituated neonates to either a stationary cross or a stationary triangle, and subsequently showed both of these stimuli side-by-side, both moving back and forth. The novel stimulus was consistently preferred, indicating recognition of the familiar stimulus despite the change from being stationary to motion. However, in another experiment, neonates failed to make the same discrimination when the objects rotated. These findings, together

![Fig. 7.1. Stimuli presented to neonates in a face perception experiment. The neonates seemed to prefer the "face" stimulus, laterally tracking it farther than any of the others. Note the similarity between the face and some of the others, in terms of feature type ("linear") and placement of "blobs" ("config"). Apparently neonates are sensitive to both features and their placement. (Adapted from Johnson et al., 1990).](image-url)
with other studies described later, suggest that object identity may be present in rudimentary form at birth but undergoes development throughout the first year.

Neonates seem to have difficulty accurately perceiving occlusion. In a study of perception of partly occluded objects, Slater et al. (1990) habituated neonates to a display consisting of a rod, moving back and forth, whose centre was occluded by a box (Fig. 7.2). After habituation, the infants viewed two test displays with no occluder, one a complete rod, and the other a broken rod (i.e. with a gap in the location previously covered by the box). The infants consistently looked longer at the complete rod, indicating that the rod parts in the habituation display were perceived as disjoint. That is, the complete rod was experienced by the neonates as novel, and the broken as familiar (recall that infants typically prefer a novel stimulus after habituation). Thus neonates apparently do not perceive partly occluded objects as consisting of both visible and invisible portions. Rather, they seem to respond only to what they see directly. This finding was recently replicated with displays that were quite rich in visual cues, such as a large depth difference between the rod, box, and background, small occluder size, and textured (i.e. patterned) background, all designed to heighten the contrast between the objects and thus facilitate perception of object unity. The neonates did not seem to take advantage of the extra visual information in the displays, still preferring the complete rod after habituation (Slater, Johnson, Brown, & Badenoch, 1996; Slater, Johnson, Kellman, & Spelke, 1994).

Returning to our earlier question, do neonates display evidence of object knowledge? The answer depends on how one defines object knowledge. One standard of object knowledge is distinguishing proximal from distal stimuli. The proximal stimulus is the stimulus itself— in this case, the pattern of light falling on the retina. The distal stimulus consists of what is represented by the pattern of stimulation— in this case, the object itself. Neonates distinguish proximal from distal stimuli when they demonstrate size and shape constancy: the object is perceived accurately, despite changes in its retinal image.

Another standard of object knowledge is going beyond what is immediately perceptible, using inference to assess the proximal stimulus. Neonates have not been found to infer hidden portions of objects, as we saw in their apparent failure to perceive object unity. Thus, there is only mixed empirical support for object knowledge in the youngest humans. (Of course, it is possible that more mature levels of object knowledge are present in neonates, but were not revealed by the studies presented earlier.)

Object knowledge develops rapidly over the first year of life. Although neonates may be limited in object perception and object knowledge by deficits in visual skills, such skills emerge so quickly that it seems unlikely that older infants are limited in the same way. Thus, in the ensuing discussions of older infants, we will consider visual skills as being sufficiently developed so as to not hinder the emergence or expression of object knowledge. Differences between age groups may lie, rather, in attention to visual information, interpretation of visual information, and/or knowledge of the physical properties of objects.

FIG. 7.3. (A) Rod-and-box display shown to infants to test perception of object unity. The rod parts undergo common motion behind the box. Adults report that the rod parts seem to be connected, forming a partly occluded surface. (B) Complete rod test display. (C) Broken rod test display. Both test displays move in like manner to the rod parts in the test display. See text for details. (Adapted from Kellman & Spelke, 1983.)
OBJECT PERCEPTION AND OBJECT KNOWLEDGE IN THE 2- TO 3-MONTH-OLD

The 3-month-old is a very different person than he or she was at birth. In many infants, the period from 2 to 3 months of age sees the advent of such milestones as more regular patterns of sleep, wakefulness and attentiveness, improvements in neurological control of volitional movements and posture, and social interaction and smiling (see Prechtl, 1984). There is also evidence that object knowledge is elaborated during this time.

Two-month-olds, unlike neonates, have been shown to perceive the unity of partly occluded objects. This implies inferential skills, and perception of occlusion and depth. In an habituation study, Johnson and Aslin (1995) presented rod-and-box displays to 2-month-olds, and followed with complete and broken rod test displays (Fig. 7.4A). In contrast to neonates, the 2-month-olds consistently looked longer at the broken rod, suggesting that they had received the impression of a complete rod behind the box in the habituation display. (Interestingly, there was no actual depth in these displays, which were computer-generated, presented on a two-dimensional television screen.)

Perception of object unity undergoes considerable development after 2 months, and seems somewhat tenuous at this age. In another object unity study with 2-month-olds, Johnson and Náñez (1995, Experiment 2) used a larger occluder relative to that employed by Johnson and Aslin (1995), and found no consistent preference for either the broken or the complete rod (Fig. 7.4B). Thus unity apparently is not perceived when less of the rod's surface can be seen, suggesting that 2-month-olds' attentional skills are limited: increased occluder size may make it more difficult to note, for example, that the two rod parts' edges are aligned, that the rod surfaces move together, and so on. As we will see, the object unity task has been used with older infants to further explore young infants' object perception.

Although 2-month-olds seem to perceive objects in depth, it is presently unknown how this is accomplished. Do they attend to the common motion of the rods' surfaces to determine segregation and depth ordering? Do they analyze differences between surfaces, in terms of colour, texture, and boundaries? Studies described later suggest the answer to the first question is yes. A study by Kestenbaum, Termine, and Spelke (1987) suggests the answer to the second question is no. Kestenbaum et al. presented 3-month-olds with displays consisting of two objects arranged in depth. From the infant's vantage point, the smaller object was closer and its boundaries were contained within the boundaries of the larger object (Fig. 7.5). Each object was covered with a different patterned texture. The infants saw these objects either separated or adjacent in depth. After habituation, the infants viewed test displays with the same two objects in novel arrangements. In one test display, both objects were displaced closer to the infant ("two forward"); in the other test display, only the nearer object was displaced ("one forward"). Kestenbaum et al. (1987) reasoned that if the infants segregated the objects in the habituation display by analysing differences in surface textures or boundaries, then the infants who saw either the separated or adjacent arrangement would look longer at the

![Fig. 7.4](image1)

(A) Rod-and-box displays used to test perception of object unity in 2-month-olds. In both (A) and (B), the rod parts underwent common motion. After habituation, the infants were shown complete and broken rod test displays. Consistent preference for the broken rod occurred only after habituation to (A), suggesting that seeing more of the rod's surface facilitates perception of object unity in this young age group. (Adapted (A) from Johnson & Aslin 1995, and (B) from Johnson & Náñez, 1995.)

![Fig. 7.5](image2)

Fig. 7.5. Schematic depictions of the objects shown to 3-month-olds in a study of object segregation. (A) Side view of the adjacent objects display. (B) Side view of the separated objects display. After habituation, the infants viewed (C) the two forward and (D) one forward displays. See text for details. (Adapted from Kestenbaum et al., 1987.)
one forward test display, because of its novel arrangement. However, only the infants who were habituated to the separated arrangement looked longer at the one forward display. This suggests that the infants did not use colour, texture, and size differences to segregate the objects in the habituation display (as adults would). Rather, they only perceived the objects as separate entities when there was an actual depth difference. This study provides corroborative evidence that very young infants perceive objects in depth, but are limited in their capacity to do so.

There is also evidence that 2- to 3-month-olds demonstrate some knowledge of objects' physical properties. Spelke, Breinlinger, Macomber, and Jacobson (1992, Experiment 3) investigated 2.5-month-olds' knowledge of continuity and solidity, which are constraints on object motions. These constraints dictate that objects in motion move on an unobstructed path, and will not pass through the space occupied by another object. The infants were habituated to events in which a ball rolled behind a screen (Fig. 7.6). The test events were similar, except a barrier was placed in the object's path. The ball either stopped at the barrier (the “consistent” event), or appeared to have rolled beyond it (the “inconsistent” event), after the ball was revealed. The infants looked longer at the inconsistent event, suggesting that they found this event unusual, perhaps because it violated their expectations of continuity and solidity.

What, then, is the state of the infants' object perception and object knowledge by the time he or she is 3 months of age? Even though few studies are available of infants this young, they provide evidence indicating much progress since birth. Whereas the neonate appears to have only rudimentary object knowledge, the 3-month-old has been found to perceive depth relations and occlusion. This is a major advance on the way to experiencing the visual array as consisting of more than meets the eye (no pun intended!). Moreover, infants at this young age are beginning to appreciate objects' physical properties.

![FIG. 7.6. Schematic depictions of events shown to 2.5-month-olds in a study of knowledge of object continuity and solidity. (A) Habituation event. (B) Consistent test event. (C) Inconsistent test event. The infants looked longer at (C), suggesting sensitivity to continuity and solidity. (Adapted from Spelke et al., 1992.)](image)

7. OBJECT PERCEPTION AND OBJECT KNOWLEDGE

OBJECT PERCEPTION AND OBJECT KNOWLEDGE IN THE 4- TO 6-MONTH-OLD

I have described fundamental changes from birth through 3 months of age. Studies to be discussed in this section report continuing developments in infants' abilities to segregate visible surfaces. Perhaps most notable, however, is the wealth of evidence concerning knowledge of objects' physical properties after 4 months of age, including awareness of the existence, location, and size of occluded objects, as well as object support and object identity.

Studies of infants' perception of object unity were originally undertaken to explore the visual cues used by 4-month-olds in determining whether two surfaces are joined behind an occluder (Kellman & Spelke, 1983; Kellman, Spelke, & Short, 1986). A reliable preference for the broken rod occurred only when the two surfaces, above and below the box, moved together (either back and forth, up and down, or backwards and forwards in depth). However, when the displays were stationary, or when the box moved with the rod surfaces or by itself, there was no consistent preference for either test display (Fig. 7.7).

Kellman and Spelke (1983; see also Kellman, 1993) interpreted these

![FIG. 7.7. Displays shown to 4-month-olds in studies of perception of object unity. The infants demonstrated preferences for the broken object after habituation to (A), (B), or (C), as well as the display depicted in Fig. 7.3A, but there was no preference after habituation to (D), (E), or (F). Thus, common motion of the surfaces above and below the occluder seems to be an important cue to perception of unity. (Adapted from Kellman & Spelke, 1983, and Kellman et al., 1986.)](image)
results by proposing that common motion of the occluded surfaces is the primary cue supporting young infants' perception of object unity. Johnson and Aslin (1996) explored the possibility that other cues also contributed. Four-month-olds were habituated to two-dimensional rod-and-box displays in which there was no background texture, or in which texture was present but the rod edges were either aligned or misaligned (Fig. 7.8). There was a reliable posthabituation preference for the broken rod when the edges were aligned and texture was present, and a preference for the complete rod when the edges were misaligned so that they would not connect behind the box, if the edges were to be extended. These results suggest that a complete rod was perceived behind the box in the former case, and two disjoint rod parts in the latter case. No preference was observed in the other two cases. Note that common motion was present in all these displays. Thus, edge orientation and background texture seem to be important cues in determining unity (edge orientation may even override common motion).

Recall that Piaget proposed that not until 8 to 12 months of age do infants maintain awareness of an occluded object's continued existence, as revealed by their patterns of search for a previously seen object. Baillargeon and colleagues have reported a series of studies demonstrating this level of object knowledge, and more, in infants as young as 4 months of age. One of Baillargeon's most important findings involves her claim that 4-month-olds have object permanence (Baillargeon, 1987). Infants were habituated to a screen that rotated through 180° (Fig. 7.9). During test, a box was placed behind the screen, so that when the screen rotated back again, it should have stopped rotating at the point where it contacts the box. The experimenter surreptitiously removed the box on some trials, however, and the infants looked longer at this event than an event in which the screen stopped rotating where the box was located, perhaps because the former event was unexpected. Because the box was completely occluded by the screen, this finding suggests that the infants represented the box's continued existence and location, and understood that the screen could not move through the space occupied by the box.

Baillargeon and DeVos (1991) reported evidence that 3.5-month-olds represent the size of a hidden object. Infants were habituated to two events presented in alternation, both involving a toy car moving left and right, periodically becoming occluded behind a screen in front of its path. The car was either tall or short. After habituation, the infants viewed two test events in alternation, similar to the habituation event. In both events, there was a window at the top of the screen. One of the events was "impossible": the tall car was not visible in the window as it travelled behind the screen. In the "possible" event, the short car was not visible in the window either, but this was not impossible because it was too short to reach the window. The infants looked reliably longer at the impossible event. This suggests that the infants represented not only the hidden object's continued existence, but its height as well.

Young infants have been found to demonstrate awareness of support relations between objects. Needham and Baillargeon (1992) showed 4.5-month-old events in which a hand brought a box into view, and withdrew,
leaving the box. The box was deposited either on top of a second box, or seemingly in mid-air without support, an impossible event (produced with the aid of support from behind, unseen by the infant). The infants consistently looked longer at the impossible event, suggesting that they expected the box to fall if unsupported.

The final study to be discussed in this section concerns object identity. Recall that object identity incorporates understanding that an object remains the same entity if it changes location or becomes temporarily occluded. It follows that an object that is similar in appearance, but located in a different part of the visual field, is a separate object, if the original object did not move on a continuous path to the new object's location. Evidence for infants' understanding of the first and second aspects of object identity was described earlier (Slater et al., 1985; Baillargeon, 1987). Evidence for the third aspect of object identity was reported by Spelke and Kestenbaum (1986, cited in Spelke, 1988). Four-month-olds were habituated to one of two events with two vertically oriented occluders. In the continuous event, a single object moved back and forth behind the occluders (Fig. 7.10). In the discontinuous event, two objects moved out successively from behind the screens, one at a time. To adults, the first event gives rise to the impression of a single object in motion. The second event appears to adults to contain two objects—the first object remains occluded as the second emerges. After habituation, the infants viewed test events with either one or two objects (no occluders). The infants who had been habituated to the discontinuous event looked reliably longer at the one-object event, indicating that they received the impression of two objects, one of which was always occluded. Infants who viewed the continuous event did the opposite. This suggests that infants who saw the continuous event inferred that only one object moved behind the occluders, whereas infants who saw the discontinuous event inferred that two objects were involved. (Evidence is presented later suggesting that object identity undergoes further development throughout the first year.)

OBJECT PERCEPTION AND OBJECT KNOWLEDGE IN THE 7- TO 12-MONTH-OLD

The major accomplishments during the last half of the infant's first year consist mainly of embellishments of perceptual and cognitive skills that have already been attained, as revealed by studies of older infants' perception of object unity, knowledge of support and gravity, and object identity.

Recall that the 4-month-olds observed by Kellman and Spelke (1983) did not seem to perceive object unity unless the partly occluded surfaces underwent common motion behind a stationary occluder. Craton (1996) reported that at 6.5 months of age, infants perceived object unity in stationary displays. This finding obtained after habituating 5.5- and 6.5-month-olds to partly occluded rectangle displays, followed by test displays consisting of broken and complete rectangles. The younger infants displayed no preference, but the older infants preferred the broken rectangle.

Craton (1996) also investigated infants' perception of the form of the hidden region. Infants aged 5.5, 7, and 8 months were presented with a stationary partial occlusion display until habituation. Test displays consisted of a connected rectangle and a cross (Fig. 7.11). The latter test display would be unexpected if the infants perceived the whole rectangular shape with a boundary interpolation process, by which the boundaries of the visible regions were perceptually extended behind the occluder (Kellman & Shipley, 1991). Only the 8-month-olds preferred the cross, suggesting that they found the cross novel and the rectangle familiar. Thus infants between 2 and 8 months perceive the unity, but not necessarily the form, of partly occluded objects, whereas 8-month-olds perceive both unity and form.

Recall that 4.5-month-olds were found to be sensitive to violations of support relations (Needham & Baillargeon, 1993). Baillargeon and Hanco-Summers (1990) investigated the conditions under which older infants would respond to adequate and inadequate support. Infants between 7.5 and 9.5 months were shown displays consisting of three boxes, arranged such that one box was in contact with two boxes below (Fig. 7.12). Each
infant saw two events: in the possible event, one of the lower boxes was moved, but the top box maintained adequate support, and thus should not be expected to fall. In the impossible event, the other lower box was moved, such that there was only a small amount of contact remaining with the top box. The infants looked longer at the impossible event, suggesting that they expected the top box to fall without adequate support. However, in another experiment, infants did not distinguish between possible and impossible events that differed in the balance of the top object. Thus infants’ understanding of support relations undergoes development after 9.5 months of age.

Infants’ sensitivity to gravity was investigated by Kim and Spelke (1992), who habituated 5- and 7-month-olds to one of two events, in which a ball rolled either down or up an inclined plane (“speeding up” or “slowing down” conditions, respectively). When the ball rolled down, it accelerated, and when it rolled up, it decelerated (adults report these changes in speed appear natural). The infants were then presented with test events in which the incline changed (from down to up, or from up to down), and both acceleration and deceleration of the ball were shown, in alternation. Only the 7-month-olds responded during test by looking longer at the unnatural event, even though the speed of the ball in that event was familiar. Thus 7-month-olds, but not 5-month-olds, seemed to understand that an object rolling down a hill accelerates, whereas an object rolling up a hill decelerates.

The final study to be discussed concerns object identity. Xu and Carey (1996) provide evidence that full object identity is not attained until 12 months of age. Ten- and 12-month-old infants were familiarised with events
in which two distinct objects were repeatedly brought out from behind a screen, one at a time (Fig. 7.13). To adults, this gave the impression of two objects behind the screen. After familiarisation, the infants were shown one- and two-object displays in alternation (no screen). In previous experiments, Xu and Carey had noted a strong baseline preference for two objects versus one object – that is, infants find two objects more interesting than one, regardless of any familiarisation period. If the infants expected two objects to be involved in the familiarisation event, they should look longer at the one-object test event. However, because of the strong baseline preference for two objects, it might be more likely that this novelty preference would be manifested by an equivalent preference for both displays (i.e. the baseline and novelty preferences would “pull” the infants’ interest in different directions, cancelling each other). The 10-month-olds showed a preference for two objects during test, no different from baseline. The 12-month-olds, on the other hand, showed an equivalent preference for the one- and two-object test displays, suggesting that the one-object display was novel (although the two-object display was still rather interesting).

This intriguing finding indicates that when 10-month-old infants view two distinct objects appearing at different times from behind an occluder, they do not seem to form an impression of two objects – rather, they appear satisfied thinking there may be only one object! Xu and Carey (1996) account for this result by suggesting that although 10-month-olds have a concept of object, they do not seem to have a concept of individual objects (sortals) that can be distinguished on the basis of appearance. This finding is especially interesting in light of the fact that even neonates can distinguish objects based on appearance – that is, they will habituate to one object and dishabituate to another. However, this does not necessarily mean that objects are thought of as stable in appearance, an important aspect of object identity.

CAVEATS: THE PROBLEMS OF REPLICABILITY AND DISAGREEMENT BETWEEN STUDIES

I have highlighted the results of dozens of studies in the preceding sections of this chapter. (This list of studies is far from exhaustive. For example, I have omitted studies of infants’ perception of number and causality, and categorisation abilities.) On the basis of these findings, today’s commonly accepted view is that in his or her first year the infant is highly competent in the perception and knowledge of the world and its objects. This view is not universally accepted, but it is supported by the majority of the evidence. In this section, I discuss problems that are faced in interpretations of some of the data presented earlier, in terms of failures to replicate reported results, and disagreements between outcomes of studies.

Good scientific studies have three characteristics: they are objective, they are based on measurable phenomena, and they are replicable. The last point is especially important in a relatively new field of endeavour, such as the study of infants’ perceptual and cognitive abilities. (Systematic studies of infant visual perception only began about 35 years ago; see Fantz, 1961.) Many of the findings described earlier have been replicated under various conditions. However, others have not been as replicable.

An example of a phenomenon that has been widely replicated is infants’
perception of object unity. Since the publishing of Kellman and Spelke's original studies in 1983, there have been over a half-dozen reports of similar findings, by investigators in different laboratories, using somewhat diverse techniques (e.g. real objects vs. computer-generated displays) with infants at various ages. Such a pattern of consistent results suggests that perception of object unity is a reasonably robust phenomenon, and argues persuasively that it is representative of infants' "true" abilities.

A phenomenon that has not been as widely replicated is the surprise infants demonstrate when one object seems to pass through the space occupied by another object. Baillargeon has reported several instances of replications of the rotating screen study (e.g. Baillargeon, 1987). However, other investigators have found this effect difficult to replicate. For example, Cohen (1995) cites an instance in which 8-month-olds did not seem surprised by a computer-generated event in which a ball appeared to roll straight through a solid wall! The point here is not to call into question the results of any study or series of studies, but rather to impart a sense of healthy scepticism, and to underscore the importance of the generalisability of an effect to its acceptance.

A problem related to replicability is sets of studies that produce conflicting results. For example, Needham and Baillargeon (1993) reported that 4-1/2 month-olds looked longer at an event in which a hand deposited a box seemingly in mid-air, compared to when the box rested on a surface. In an investigation of infants' understanding of object continuity, Spelke et al. (1992, Experiment 4) showed 4-month-olds an event in which a ball dropped behind a screen, and was later revealed to be resting on the floor, or seemingly floating in mid-air (it was supported from behind). In contrast to what would be expected on the basis of Needham and Baillargeon's results, the infants did not look longer at the impossible event. Needham and Baillargeon suggest that perhaps the infants observed by Spelke et al. did not show surprise at the lack of support because they were somehow able to infer the presence of hidden support. At minimum, these conflicting results suggest that this level of object knowledge is fragile in its early form.

The problem of disagreement is not limited to these two studies. In many cases, studies of a newly discovered phenomenon will produce conflicting results. This is often due to methodological issues, as it may be in the example given earlier. But it also suggests, again, that it is wise to maintain a sceptical attitude.

THEORETICAL ACCOUNTS OF THE DEVELOPMENT OF OBJECT KNOWLEDGE

I have contrasted Piaget's theory with an account of burgeoning visual skills, thereby implying that much learning about the world must necessarily take place by observing objects and events over the first year of life.

7. OBJECT PERCEPTION AND OBJECT KNOWLEDGE

I think this is accurate, but this view is not yet well specified, and it should not be considered a proper theory of the development of object perception and object knowledge. The two most well-known theories of these phenomena are those of Elizabeth Spelke and Renee Baillargeon. These researchers take contrasting views of early cognitive development.

Spelke (1994; Spelke & Van de Walle, 1993) proposes that a system of "core principles" guides infants' perception and knowledge of objects from birth. These principles arise from an intuitive, innate theory of objects and their physical properties. Spelke's view discounts distinctions between perception and knowledge in infants, stressing instead that understanding the world is based on intuitions of objects as obeying certain constraints, the principles of cohesion, contact, and continuity. For example, perception of object unity, on this account, arises from the tendency to assign visible surfaces to the same object, if the surfaces undergo common motion and lead behind an occluder (the principle of contact; surfaces move together if and only if they are in contact). Spelke adds that early knowledge encompasses fundamental environmental constraints, the highly reliable ways in which objects behave. Because our ancestors evolved under these same constraints, natural selection may have endowed humans with innate knowledge that captures their essence.

Support for Spelke's view comes from parallels between infants' and adults' physical knowledge. For example, adults do not expect an object to travel from one place to another without following a continuous path between places (the principle of continuity). We have seen that 4-month-olds seem to have the same expectation (Spelke, 1988). However, adults often have difficulty with appropriate expectations of object inertia, a constraint dictating that moving objects travel on straight paths until they come to rest. Kaiser, McConkey, and Proffitt (1986), for instance, found that many adults expect a ball that rolls out of a curved tube to continue following a curved trajectory. Likewise, infants' understanding of inertia seems less well-developed than other kinds of physical knowledge. Spelke, Katz, Purcell, Ehrlich, and Breinlinger (1994) reported that sensitivity to inertia appears to emerge quite gradually. Even at 10 months of age, infants did not seem to reliably expect a moving object to come to rest in a predictable spot behind an occluder.

In contrast to Spelke, Baillargeon (1994) describes the development of object perception and object knowledge in terms of innate mechanisms that guide learning. When infants first learn about a new physical phenomenon, they form a preliminary, "all-or-none" initial concept that captures the essence of the phenomenon but few of its details. Added experience leads to the identification of relevant variables with which the initial concept is elaborated. For example, infants initially expect unsupported objects to fall, unless there is some contact with another surface.
(Needham & Baillargeon, 1993). This initial concept may arise from the many experiences infants have watching objects drop, experiences that are ubiquitous and available from birth. With further experience, such as manual exploration, and placement of objects on surfaces, infants may realize that the amount of contact is important in predicting whether an object will fall. Thus amount of contact becomes a relevant variable in understanding of support relations. We have seen that 7.5- to 9.5-month-olds are sensitive to amount of contact as important in support relations (Baillargeon & Hanko-Summers, 1990), but do not seem to realize that balance is also involved, a variable that may require even more experience to be identified.

Evidence for Baillargeon's (1994) view comes from patterns of learning of a variety of other physical phenomena, such as collision and "unveiling" (revealing an object under a cloth cover). At 2.5 months of age, infants demonstrate understanding that a wheeled toy should roll when hit by another object. However, it is not until after 3.5 months of age that infants seem to make judgements about how far the toy should roll, based on the size of the object that strikes it. At 9.5 months of age, infants seem to understand that a protuberance under a cloth cover signifies an object underneath, but not until 12.5 months do they judge the hidden object's size based on the size of the protuberance.

Note that both Spelke and Baillargeon postulate innate skills that contribute to object perception and object knowledge. Spelke in the form of concepts and Baillargeon in the form of mechanisms for learning. That is, the infant brings something to the task of knowing the world. Knowledge does not arise from nothing – the infant is not considered a "blank slate". For Spelke, development is a process of enrichment of initial conceptions. For Baillargeon, development is a process of applying learning mechanisms to available data. Both theories are highly attractive and intriguing, and each can account for a proportion of the data presented here.

Nevertheless, each theory has its problems. For example, Spelke's (1994) postulated core principles fail to account for the development of perception of object unity. Recall that the contact principle dictates that surfaces that move together must be connected. We have seen that neonates do not seem to perceive object unity in displays with rod parts undergoing common motion (Slater et al., 1996). Moreover, 4-month-olds do not perceive unity in displays in which the rod parts are misaligned (Johnson & Aslin, 1996). Spelke's theory also has difficulty explaining why gravity is not a core principle. This is a fundamental constraint on object behaviour, but infants do not seem sensitive to gravity until after 5 months of age (Spelke et al., 1994).

Baillargeon's (1994) theory of innate learning mechanisms does not adequately capture innate perceptual abilities, such as size and shape constancy (Slater et al., 1990; Slater & Morison, 1985), nor can it provide an account of neonates' preference for faces (Johnson et al., 1991). (In fairness, it should be noted that Baillargeon limits her theory to infants' physical knowledge.) It is clear that both theories provide important ways of looking at infants' perceptual and conceptual skills, and although both successfully capture some aspects of the development of these abilities, neither furnishes a complete account on its own.

CONCLUSIONS

The studies presented in this chapter portray infants as limited in many aspects of object perception and object knowledge but highly competent in others, and certainly capable of rapid learning about objects and their properties. It seems as if the most rapid period of development of these skills is in the first few weeks of life. For example, consider the emergence of perception of object unity. Neonates apparently only respond to what they see directly, not inferring the unity of the rod parts even in displays rich in visual cues. Within 2 months, this ability has emerged. How does this happen? (This question may seem reminiscent of the questions I asked earlier in the chapter.)

The precise mechanisms of visual learning remain a mystery. Are cognitive abilities limited by poor visual skills? That is, does suboptimal vision prevent infants from effectively sampling the visual array, thus depriving them of the opportunity to abstract information about objects? Or are visual skills limited by poor cognitive abilities? That is, does inefficient attention prevent infants from attending to the most informative aspects of the environment? It may be that these questions themselves are ill-founded. They are certainly based on my view that visual learning is of primary importance to humans. Other researchers might disagree. My goal with this discussion is not to answer all the questions, but rather to leave you with a sense of wonder about how it is that you perceive and know so much, and how that came to be.

REFERENCES