Audrey tells of an unusual preference in her healthy 9-pound newborn daughter Michelle. For the first several weeks of life, Michelle would nurse only from one breast, despite the fact that Audrey expressed milk equally well from both. Michelle’s preference was the left breast, the one over her mother’s beating heart, a sound Michelle had heard from
the time her auditory system began to function several months after conception. Michelle would nurse from the left breast only and inevitably fall asleep, presumably being soothed not only by the milk she was consuming but also by the familiar sound she was hearing.

If you ask most people what newborn babies do, the answer you’ll likely get is, “Sleep, eat, cry, and soil their diapers.” This is true enough, but newborns are also making sense of their world. They are perceiving (hearing, seeing, smelling) and learning about events that surround them, and have been for some time prior to birth. Not all that many years ago, well-informed people believed that infants enter the world unable to perceive sights and sounds. When I (DB) was teaching my first child development class as a graduate student in the early 1970s, I stated that newborns can see, meaning that they can tell the difference between two visual displays. A middle-age woman informed me that I was wrong, that newborns cannot see. She had had four children, and her obstetrician and pediatrician had both told her that babies were functionally blind at birth and learned to see during their first month of life. Newborns are far from mental giants, but they do enter the world able to perceive information with all their senses. Furthermore, babies have some perceptual biases. Some sights, sounds, and smells are inherently more pleasing to them than others, and they learn to prefer additional sensations during the first weeks of life.

But infants, even newborns, do more than perceive their world. As the example of Michelle suggests, they are also learning, something that most people call cognition. Even among experts, it’s not always easy to know where perception ends and cognition begins (see, for example, L. B. Cohen & Cashon, 2006, for a review). Perception is usually defined as involving the organization of the sensations (for example, sights, sounds, smells), whereas cognition deals more with what we do with those perceived sensations (for example, classifying items or events into categories, solving problems, memorizing). In this chapter, we first examine the developing perceptual abilities in infants and then look at some basic cognitive abilities, focusing on aspects of what has been called core knowledge—specifically, infants’ understanding of object representation and babies’ abilities to make sense of quantitative information. Other topics related to infant cognition are examined in later chapters.

**BASIC PERCEPTUAL ABILITIES OF YOUNG INFANTS**

The study of infant perception has been one of the most successful endeavors in the field of cognitive development over the past half century (see S. P. Johnson & Hannon, 2015). What infants perceive and know was once thought to be beyond the limits of science. However, the development of often simple techniques—using behaviors that infants, even newborns, can control themselves to peek into their minds—has permitted developmental psychologists to get a relatively clear picture of what infants perceive and how their perceptions change over time.

Most research on infant perceptual development has concerned audition (hearing) and
vision. This is partly because of the importance of these two senses for human information processing and because vision in particular shows substantial development during the first year of life. The development of audition and vision are discussed in separate sections later in this chapter.

Research on other senses has also been conducted, of course. For example, it was once believed that newborns were relatively insensitive to pain. More recent research, however, clearly demonstrates that they do, indeed, perceive pain (Delevati & Bergamasco, 1999), and some evidence indicates that, for extremely low birth weight (ELBW) infants (below 1,000 grams, or about 2.2 pounds), their response to pain is affected by repeated painful episodes, which are often necessary for preterm infants (Grunau et al., 2001). When tested at 8 months of age, the number of invasive procedures ELBW infants had from birth was associated with reduced facial and heart-rate reactions to pain (blood collection). Yet other studies report that children who were exposed to more pain as preterm infants experience increased sensitivity to pain in childhood and adolescence, compared to their full-term peers. Fortunately, these threshold differences do not seem to persist into adulthood; adults’ self-reports indicate there is no increased prevalence of pain syndromes for those born at extremely low birth weight (see Grunau, 2013, for a review). Newborns also respond to another skin sense, that of touch, or tactile stimulation. Actually, research with both animals and human preterm infants indicates that tactile stimulation is important in ameliorating pain responses in particular and promoting normal growth and development in general. For instance, very small preterm infants who receive extra tactile stimulation gain more weight, spend more time awake, and display more advanced cognitive and motor skills than do normally treated preterm babies (see Honda et al., 2013; Schanberg & Field, 1987). This research has led to an increased prevalence of skin-to-skin care, also known as kangaroo care, in neonatal intensive care units and newborn nurseries (see Johnston et al., 2014).

The chemical senses (olfaction and taste) tend to develop early and are quite well developed shortly after (and even before) birth. In fact, a pregnant woman’s diet can influence taste preferences in her newborn. This was illustrated by a study in which some women consumed anise-flavored food during pregnancy whereas others did not. At birth and 4 days later, infants born to anise-consuming mothers showed a preference for anise odor, whereas those born to non-anise-consuming mothers displayed aversion or neutral responses to anise (Schaal, Marlier, & Soussignan, 2000). Young infants can also tell the difference among a wide range of odors early in life (Steiner, 1979), and they develop preferences for certain odors within the first week. In a study by Aidan Macfarlane (1975), for example, 6-day-old nursing babies were able to discriminate the odor of their mothers from those of other women. In this study, mothers wore breast pads in their bras between nursings. Two breast pads—one from the baby’s mother and the other from another woman—were placed on either side of an infant’s head. Although no differences in infants’ behaviors were seen in this situation at 2 days of age, by 6 days of age babies were turning to their own mother’s pad more often than to the pad of another woman. That is, not only can babies discriminate odors, they quickly learn to make associations with odors and to modify their behavior accordingly. In subsequent work using a procedure similar to that of Macfarlane,
researchers found that infants develop a preference for the odor of milk versus amniotic fluid (which they had been living in for 9 months) by 4 days of age (Marlier, Schaal, & Soussignan, 1998) and that bottle-fed, 2-week-old infants preferred the breast odor of a lactating female to that of a nonlactating female (Makin & Porter, 1989).

Section Review

- From birth, infants actively use their perceptual systems to acquire information from their surroundings.
- By 1 week of age, babies can discriminate their mothers from other women by smell and by the sound of their voices.
- Infants also experience pain at birth and respond to tactile stimulation.
- Olfaction and taste are well developed at birth and affected by maternal diet.

Ask Yourself . . .

1. How have changes in our knowledge of infants’ perceptual abilities influenced neonatal practice?

METHODOLOGIES USED TO ASSESS INFANT PERCEPTION

How can a psychologist tell if an infant can see or hear something? That is, how can we determine if an infant can tell the difference between a bull’s-eye pattern and a checkerboard pattern, for example, or between the mother’s voice and that of another woman? This basic problem hampered serious investigation of infants’ perceptual abilities for years, but the solution is really quite simple. What one must do is find some behavior that an infant can control and then use that behavior as an entry into what babies can perceive. For example, the Macfarlane (1975) study just presented took advantage of babies’ abilities to turn their heads in one direction or another to determine if they could discriminate and develop a preference for certain odors. Such measures are considered implicit measures of infant cognition because they are thought to capture aspects of cognition that are unconscious and cannot be expressed directly or verbally. As we’ll discuss, these aspects include implicit memory, such as familiarity. In contrast, explicit measures require that the participant report on the contents of his or her cognition or behave in observable ways that are directly related to the task at hand. Because infants lack sophisticated verbal ability and behavioral control, many of the techniques we discuss next are considered implicit measures of cognitive functioning. The distinction is important to introduce however because, as you’ll see, the responses of infants (and the conclusions drawn about their cognitive abilities as a result) often differ based on whether implicit or explicit measures are used.

“This Sucks”: Using Infant Sucking to Provide Insight Into Infant Perception

Another behavior that very young infants can control is sucking. How might researchers use this behavior to tell if babies can discriminate between two different auditory signals? Anthony DeCasper and Melanie Spence (1986) used infants’ ability to regulate their sucking to examine whether infants were learning something about the outside world while still in utero. DeCasper and Spence asked pregnant women to read aloud one of three passages twice a day during the last 6 weeks of their pregnancies. Shortly
after birth, the neonates were tested for which passage, if any, would have more reinforcing value. Headphones were placed over the babies’ ears, and various passages were played to the infants. Nonnutritive sucking (that is, sucking on a pacifier) was assessed as a function of which passage was being played. First, a baseline sucking rate was determined for each baby (that is, how rapidly the infant sucked on a nipple when no passage was being played). Then, babies were trained such that changes in their rate of sucking determined whether they heard a familiar passage (the one their mothers had read during pregnancy) or a novel passage (one their mothers had not read). Some infants heard the familiar passage when they increased their sucking rate, whereas the contingency was reversed for other infants. The general finding was that the familiar passage was more reinforcing than the novel passage; infants were more likely to alter their sucking rate to hear the familiar passage than to hear the novel passage. Furthermore, the reinforcing value of the passage was independent of who recited it, an infant’s mother or another woman. These results present unambiguous evidence of prenatal conditioning to auditory patterns. The infants were able to discern the auditory characteristics (the rhythm and sound pattern) of these often-repeated passages, and the researchers were able to determine this by associating the various passages with changes in a behavior that infants could control themselves (sucking rate).

**Visual Preference Paradigm**

The simplest (and first) technique to test infants’ visual discrimination abilities was developed by Robert Fantz (1958, 1961). He placed alert babies in a looking chamber. Series of visual stimuli were placed in front of infants’ eyes, and an observer peeking through a hole in the chamber above the infant recorded which stimuli the baby looked at the most. If groups of infants spent significantly more time gazing at one pattern than at another, it could be assumed that they can differentiate between the two patterns and prefer to look at one relative to the other. If they couldn’t tell the difference between the paired stimuli, there would be no difference in their looking behavior. Using this visual preference paradigm, Fantz was able to show that babies younger than 1 week can tell the difference between stimuli such as a schematic face, a bull’s-eye pattern, and an unpatterned disk (see Figure 4.1).

![Figure 4.1 Infants’ visual attention to different patterns.](image-url)
We use the term *preference* not to reflect a conscious liking for one thing over another—for alternative rock versus country music, for example—but only to indicate that an infant looks at one object more than another. *Preference*, as used here, is synonymous with *perceptual bias* and merely reveals that infants are not responding randomly.

If infants failed to show a preference (or perceptual bias) between two items, however, this would not necessarily mean that they could not tell them apart. Perhaps both are equally interesting. But if infants have no preference for one stimulus over another, how can you tell if they can discriminate between them? One technique is the habituation/dishabituation paradigm, which we now describe.

### Habituation/Dishabituation Paradigm

A somewhat more complicated procedure is often used to evaluate infants’ perception, memory, and concepts, and this is the *habituation/dishabituation paradigm*. Habituation refers to the decrease in response as a result of repeated presentation of a stimulus. The first day on the job in a noisy factory, for example, produces increased levels of physiological stress (for example, elevated heart rate and blood pressure). After a week in this environment, however, levels of stress decline, even though the noise remains. This is habituation. Dishabituation (sometimes referred to as *release from habituation*) occurs when, following habituation, a new stimulus is presented that increases the level of responding. If we switch from Factory A to Factory B, for instance, levels of physiological stress rise, even though the new factory is no louder than the old one was. The noises are different, however, which causes an increase in responding, or a release from habituation.

How does this phenomenon relate to infant perception? The amount of time babies look at visual stimuli (or orient to auditory stimuli) is analogous to the worker’s physiological reactions to loud noise. The longer infants are exposed to a visual stimulus, the less time they spend looking at it. Habituation is said to occur when an infant’s looking time is significantly less than it was initially (often defined as when visual fixation to the stimulus is 50% of what it was on the early trials). At that point, a new stimulus is presented. If attention (that is, looking time) increases from the level of immediately before, dishabituation is said to occur. A typical habituation/dishabituation curve is shown in Figure 4.2.

What does such a pattern mean? First, it demonstrates that infants can discriminate between the two stimuli. Babies might not prefer one to the other, but that they respond to the new
stimulus with increased attention indicates they can tell the difference between the two. This paradigm is very useful in determining infants’ discrimination abilities when researchers are using stimuli for which babies might not have a decided bias. Habituation and dishabituation also indicate memory. Infants are making a discrimination between one stimulus that is physically present and another that is present only in memory. They are not choosing between two stimuli that are before them but between one stimulus that is in front of their eyes and another that is only represented in their minds.

Using this procedure, evidence of habituation/dishabituation (and, thus, of rudimentary memory) has been found in newborns for vision (S. Friedman, 1972) and haptic perception (identifying an object by active touch) (Streli, Lhote, & Dutilleul, 2000). Moreover, fetuses as young as 30 weeks habituate and later dishabituate (as demonstrated by their movement) to vibrations delivered via sound waves through the mother’s abdomen (Dirix et al., 2009; Sandman et al., 1997). In one of the first studies to demonstrate habituation/dishabituation in newborns, Steven Friedman (1972) habituated 1- to 3-day-old infants to one visual pattern and then, immediately after habituation, showed the babies a novel pattern. These neonates displayed the classic increase in responding to the new stimulus, indicative of memory (be it ever so brief).

One word of caution about Friedman’s results is in order, however. Of 90 newborns initially tested, 50 were excluded for reasons such as crying and falling asleep. Of the 40 remaining, only 29 displayed dishabituation. Thus, only 32% of the original sample demonstrated the habituation/dishabituation phenomenon. The high dropout rate challenges the generalizability of Friedman’s (and others’) findings. What Friedman’s results do indicate, however, is that visual memory is within the capability of many human newborns, although the possibility exists that many infants do not possess such memory until several weeks after birth. (Dropout rates have been lower in some more recent studies. For example, of the 34 newborns tested by Alan Slater et al. [1991], only 10 [29%] were excluded for fussiness and related problems.)

Not only can the habituation/dishabituation paradigm be used to show discrimination and memory but also concept formation. This is done by varying the stimuli presented during habituation trials. Rather than habituating infants to a picture of the face of a single individual (Sally), for example, pictures of different individuals can be presented (Sally, Maria, Barbara, and Teresa). In both the single- and multiple-face cases, looking time declines with repeated exposure (that is, habituation). In the former case, infants are habituated to a specific stimulus (Sally), and in the latter case, infants are habituated to a category of stimuli (women’s faces). After habituation has occurred, a new female face can be presented (Elizabeth). Infants who were habituated to a single face should recognize this new face as a novel stimulus and increase their attention to it (that is, show dishabituation). In contrast, infants who were habituated to women’s faces in general should recognize it as just another example of a woman’s face and continue to habituate. That is, even though they have never seen this face before, they should categorize it as familiar and direct relatively little of their attention to it.

The procedure and results just described are similar to those reported by Leslie Cohen and Mark Strauss (1979) for a group of 30-week-old infants. Cohen and Strauss interpreted their findings as evidence that such infants can abstract “appropriate conceptual categories regarding the human face” (p. 422). By continuing to habituate
to the new stimulus, infants are, in effect, telling us that although the face is perceptually different from anything they have seen before, it is similar in general form to what they already know. They are telling us that they have acquired a category for female faces. Using these and similar techniques, research during the past 40 years has shown that infants as young as 3 months can organize objects into perceptual categories during relatively brief experimental sessions (Eimas & Quinn, 1994; Younger & Gottlieb, 1988).

These are not the only methods to assess infant perception. But these methodologies have been used for more than 40 years to evaluate what babies can perceive and what they know, and most of the research reviewed in this chapter involves variants of these well-developed techniques.

Section Review

From birth, infants actively use their perceptual systems to acquire information from their surroundings. By 1 week of age, babies can discriminate their mothers from other women by smell and by the sound of their voices. A number of implicit measures have been used to assess infants’ perceptual abilities.

- Infants will alter their sucking rate to different stimuli, indicating their ability to discriminate.
- Researchers measure the amount of time infants spend looking at two stimuli in a visual preference paradigm. If infants spend more time looking at one stimulus than another, researchers can infer that infants can discriminate between the stimuli and prefer to look at one versus the other.
- Habituation occurs when infants’ looking time diminishes as a result of repeated presentation of a stimulus. Dishabituation, or release from habituation, occurs when looking time increases with the presentation of a new stimulus. Habituation and dishabituation to visual stimuli are found for some newborns and reflect both discrimination and memory.

Ask Yourself . . .

2. What are the basic visual and auditory abilities in newborns? How do these abilities develop over infancy?
3. What are the differences in implicit and explicit measures of cognition and perception?
4. How can we know what babies perceive and what they are thinking about? What are some of the more frequently used methods to assess infant perception and cognition?

DEVELOPMENT OF VISUAL PERCEPTION

When can infants begin to make sense of their visual world? When, for example, can they discriminate between two visual stimuli or form visual concepts? We, like our primate cousins, are a visual species. Survival during our prehistoric past would have been unlikely for a visually impaired child. Vision gives us information about both near and distant objects that touch and hearing cannot easily provide. Spatial cognition is an important higher-order skill (see Chapter 6), and such thinking is based on vision. Perhaps because of the importance of vision to the species, or perhaps because we’re better at thinking about ways of testing vision, visual perception has been the most studied sense in psychology, both in children and in adults.
Vision in the Newborn

Newborns can perceive light, as demonstrated by the pupillary reflex (constriction of the pupil to bright light and dilation to low levels of illumination). However, accommodation, or focusing, of the lens is relatively poor at birth, regardless of the distance an object is from an infant’s eyes, and most of what newborns look at they see unclearly (Tondel & Candy, 2008). Development of the muscles of the lens is rapid, however, and under favorable stimulus conditions, accommodation is adultlike by as early as 3 months of age.

Newborns will visually track a moving object, but their eyes will not necessarily move in harmony. Convergence refers to both eyes looking at the same object, an ability apparently not possessed by newborns (Wickelgren, 1967). Convergence and coordination (both eyes following a moving stimulus in a coordinated fashion) improve during the first months of life and are adultlike by 6 months of age (Aslin & Jackson, 1979).

Studies attempting to determine the acuity, or the ability to see clearly, of infants have yielded varied results, depending on the technique used. Acuity improves substantially during the first year of life, but it is very poor at birth (Kellman & Banks, 1998). To assess visual acuity in infants, babies are shown high-contrast patterns of various sizes, such as the pattern of stripes shown in Figure 4.3. If they look at the striped pattern longer than at a plain gray one, we infer that they can “see” the lines. When they can no longer tell the difference between the gray pattern and the striped pattern, it reflects the narrowest width of stripes that an infant can discriminate, and this is used to determine the infant’s visual acuity.

FIGURE 4.3 If infants look at a striped pattern like this one longer than at a plain gray one, we know that they can “see” the lines. When they can no longer tell the difference between the gray pattern and the striped pattern, it reflects the narrowest width of stripes that an infant can discriminate, and this is used to determine the infant’s visual acuity.

Source: © Cengage Learning.
supplemented in infant formulas, omega-3 long-chain polyunsaturated fatty acids (LCPUFAs) like those found in fish oil supplements and other “healthy fat” foods, lead to significant improvement in visual acuity by as early as 2 months of age (Qawasmi, Landeros-Weisenberger, & Bloch, 2013).

Do newborns see the world in color, the way adults do? Although newborns might not be color-blind, they apparently do not perceive much in the way of color. When differences in brightness are controlled, infants fail to discriminate among a wide range of colors until about 8 weeks of age (Allen, Banks, & Schefrin, 1988). Research has shown newborns can likely discriminate between the colors red and white but cannot differentiate blue, green, and yellow from white (R. J. Adams, Courage, & Mercer, 1994). In general, newborns seem to process color information the same way adults do, but their color vision itself is extremely poor (R. J. Adams & Courage, 1998). However, by about 4 months of age, their color perception has improved greatly and is similar to that of adults (Franklin, Pilling, & Davies, 2005; Ozturk et al., 2013).

The research just cited indicates that newborns can discriminate differences in intensity of light, can track a moving object, and likely can see differences between contrasting colors (see Photo 4.1). Can they tell the difference, however, between a checkerboard pattern and a bull’s-eye pattern? In the earlier section on methodology, we described a simple procedure developed by Fantz (1958) in which infants are shown two pictures and the time they look at the various stimuli is noted. If the chosen stimuli are sufficiently different, even very young infants will show a bias for one over the other, demonstrating by their differential looking time that they can tell the difference between the two. Because of the relatively poor acuity of young infants’ vision, however, stimuli must be reasonably discrepant before discriminations can be made, but newborns do make such discriminations (Slater, 1995).

### Development of Visual Preferences

What a baby, or anyone else for that matter, chooses to look at depends on a variety of physical stimulus characteristics as well as psychological characteristics. Physical characteristics, such
as movement, amount of contour or contrast, complexity, symmetry, and curvature of the stimulus, affect our looking behavior from a very early age. Familiarity and novelty, which determine the psychological significance of a stimulus for us, also affect the visual biases of infants, but these psychological factors increasingly influence infants’ attention from 2 to 4 months of age. Until this time, babies’ visual attention is affected chiefly (but not exclusively) by physical stimulus features.

**Physical Stimulus Characteristics**

Movement is a potent stimulus characteristic influencing infants’ visual attention. Everything else being equal, babies look more at a moving stimulus than at a comparable stimulus that is stationary. In an experiment by Marshall Haith (1966), newborns sucked on a nipple while watching a light display. On some trials, the light moved, tracing the outline of a triangle. Babies decreased their sucking on these trials relative to those when the light did not move, indicating increased attention to the moving light.

Infants are also attracted to areas of high contrast, as reflected by the outline, or contour, of an object. In a pioneering study, Philip Salapatek and William Kessen (1966) assessed the visual scanning of newborns. Infants less than 1 week of age were placed in a modified looking chamber with a white triangle painted on a black background situated before their eyes. The infants’ eye movements were recorded and then contrasted with those that occurred when the triangle was not visible. Examples of the scanning patterns of the newborns when the triangle was present are shown in Figure 4.4. As can be seen, the infants’ visual fixations were centered near the vertices of the triangles, the areas of most contrast. Subsequent research indicated substantial individual variability in newborn scanning, with many infants during the first 6 weeks of life showing no systematic visual attention to stimulus contours; much of this variation has been attributed to differences in infant neurological maturity at birth (Bronson, 1990). By about 2 months, however, infants in the Bronson (1990) study were able to consistently direct their attention toward stimulus contours. Work by Salapatek and his colleagues (Maurer & Salapatek, 1976; Salapatek, 1975) indicated that infants at 1 month of age direct their attention primarily to the outside of a figure and spend little time inspecting internal features. Salapatek referred to this tendency as the **externality effect**. By 2 months, however, most of infants’ fixations are on internal stimulus features. An example of scanning patterns of 1- and 2-month-olds is shown in Figure 4.5.

**FIGURE 4.4** Examples of scanning patterns of newborns.

![Examples of scanning patterns of newborns.](source)

Infants’ bias for and processing of symmetrical forms have been shown for vertical stimuli. Although there seems to be no bias for vertical symmetry until the latter part of the first year, infants as young as 4 months process vertically symmetrical stimuli (stimuli that are the same on the left and right sides) more efficiently than they do vertically asymmetrical or horizontal stimuli (Bornstein, Ferdinandsen, & Gross, 1981). Efficiency of visual processing in these studies was measured by rates of visual habituation. Four-month-old infants acquired information about vertically symmetrical stimuli more effectively than they acquired information about asymmetrical or horizontal information, as reflected by their faster rates of habituation (that is, they looked at the symmetrical stimuli less on later trials than they looked at the asymmetrical or horizontal stimuli). According to Marc Bornstein and his colleagues (1981), “The results . . . support the view that verticality has a special status in early perceptual development. . . . Whether innate, early maturing, or based on experience, the special quality of verticality generally may derive from the importance of the vertically symmetrical body and face” (p. 85).

Infants also have a bias to attend to “top-heavy” stimuli, with more information in the upper portion of a stimulus than the lower portion, as is typically the case with faces (Macchi Cassia, Turatin, & Simion, 2004; Turati et al., 2002). This explains, in part, infants’ greater attention to upright versus inverted faces.

Another physical stimulus feature of importance is that of curvature, or curvilinearity. Some of Fantz’s original work demonstrated infants’ biases for curved stimuli, such as a bull’s-eye pattern, over linear (that is, straight-line) stimuli of comparable contour (Fantz, 1958). Holly Ruff and Herbert Birch (1974) similarly observed a bias for curvilinear stimuli in 3- and 4-month-old infants, but they also found a bias for concentric stimuli (see Figure 4.6). This bias for curvature was reported even in a sample of newborns (Fantz & Miranda, 1975), although only when the stimuli differed in their outer perimeter (recall the externality effect).

The recent innovation of a head-mounted eye tracker has allowed researchers to glimpse the visual biases of mobile infants on the go. Using this technology, John Franchak and his colleagues (Franchak et al., 2011) found that 14-month-old infants’ visual exploration is opportunistic during free play. For instance, they reported that infants did not often look at their mothers’ faces following her infant-directed utterances, unless the mother was sitting at infants’ eye level. Infants did spend a significant amount of time gazing toward their own hand movements during manual actions and crawling, but gazing at obstacles was less common during leg movements. These findings suggest that in

**FIGURE 4.5** Examples of visual scanning of faces by 1- and 2-month-old infants. One-month-old infants explore the contour of faces, called the externality effect, whereas 2-month-olds spend more time looking at the internal features of faces.


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naturalistic settings, infants prefer to look at relevant areas in the environment to meet changing task demands. It also reminds us that we cannot ignore the interplay between physical constraints and infants’ preferences in shaping social interactions. Future studies using this technology will surely yield additional insights as to the ways infants filter the visual input during everyday interactions.

**Psychological Stimulus Characteristics**

Movement, contour, complexity, symmetry, and curvature continue to affect the attention of people throughout life. Beginning sometime around 2 to 4 months, however, the psychological characteristics of a stimulus—that is, the stimulus’s familiarity or novelty—exert an increasing influence on whether and for how long it will be attended to. The fact that a stimulus’s familiarity or novelty influences infants’ attention implies some sort of memory for the stimulus event, as we discussed when interpreting the result of dishabituation studies (L. B. Cohen & Strauss, 1979). For a stimulus to be regarded as familiar, it must be contrasted with some previous mental representation of that stimulus—that is, it must be contrasted with a stimulus that was previously known. Similarly, to be novel, a stimulus must be slightly different from something that the perceiver already knows (Rheingold, 1985).

However, it has long been known that, under some circumstances, infants actually show a bias to attend to familiar, not novel, stimuli (Bahrick, Hernandez-Reif, & Pickens, 1997; Courage & Howe, 2001). In general, a bias for familiarity typifies younger infants but also holds for older infants in the early phases of visual processing. For example, Susan Rose and her colleagues (1982; see Experiment 2 in that study) showed that groups of 3.5- and 6.5-month-old infants initially showed a bias for familiarity, followed by no preference, and eventually, a bias for novelty (see also Courage & Howe, 1998, for similar results with 3-month-olds). Other research has found that whereas 3-month-old infants preferred to look at faces from their own race (a bias toward familiarity), 9-month-old infants had a preference to look at faces from other races (a bias toward novelty) (S. Liu et al., 2015). In a similar vein, Richard Bogartz and his colleagues (Bogartz & Shinskey, 1998; Bogartz, Shinskey, & Speaker, 1997) proposed that infants prefer to look at familiar stimuli when processing is in its early stages, based on Eleanor Gibson’s (1991) differentiation theory, which posits that infants’ perception becomes increasingly specific with time, as the sense of familiarity allows them to distinguish one...
stimulus from another. It takes time to create and store memory representations, and the brain is limited on how much information it can collect in a single exposure to a novel stimulus, so infants should prefer attending to familiar stimuli while memory representations are still being formed. Once a stable memory representation has been formed, an infant’s preference should switch to a novel stimulus (see also Bahrick et al., 1997).

Richard Aslin and his colleagues (Aslin, 2014; Kidd, Piantadosi, & Aslin, 2012; see also Kidd, Piantadosi, & Aslin, 2014) have described the novelty-familiarity conundrum as the Goldilocks effect, whereby infants take an active role in sampling their environment, looking longer at stimuli that are neither too simple nor too complex (see also Kagan, 1971). Consistent with Gibson and Bogartz, Aslin argues that infants’ tendency to maintain fixation on events of intermediate familiarity, as demonstrated by their own work (which we describe later) and that of others (McCall, Kennedy, & Appelbaum, 1977), “appears to be based on [infants’] implicit sense that some patterns of information are more or less informative than others and therefore worthy of further sustained attention” (Aslin, 2014, p. 12).

### Development of Face Processing

Infants, like older children and adults, like faces. Some of the earliest work in infant visual preferences revealed that babies of 4 months and older demonstrate a preference for the human face over other nonface-like stimuli (Fantz, 1961). Infants’ preferences for physical features, such as curvilinearity and vertical symmetry, may largely account for babies’ more general bias to attend to faces.

Might a bias to attend to faces be present shortly after birth? Such a bias would not be surprising, for no single visual stimulus likely is of greater importance to a human infant than that of the face of another member of his or her own species. Human infants are highly dependent on their parents for support and protection for a far longer time than other mammals are, and human infants’ survival is made more likely by the strong social attachment they establish with their parents. Given this, it makes sense from an evolutionary perspective for infants to be oriented to the most social of stimuli, the human face.

Research following Fantz’s pioneering work pushed back the age at which infants show a preference for face-like stimuli to the newborn period. For example, Mark Johnson and his colleagues demonstrated that newborns can distinguish between face-like and nonface-like stimuli (M. H. Johnson, Dziurawiec, et al., 1991; Morton & Johnson, 1991). These studies did not use a visual preference paradigm, however. Rather, they showed infants different head-shaped stimuli, moving each stimulus across the babies’ line of visual regard. Investigators measured the extent to which the infants followed each moving stimulus (a) with their eyes and (b) by turning their heads. Using these measures, other researchers have reported significantly greater eye or head movement to face-like stimuli than to nonface-like stimuli for infants ranging in age from several minutes to 5 weeks. (Figure 4.7, from M. H. Johnson, Dziurawiec, et al., 1991, presents the results of one such study.) Subsequent research using related methodologies has found special attention for face-like stimuli for newborns (Easterbrook et al., 1999; Mondloch et al., 1999).

Such evidence suggests that infants are born with some notion of “faceness” and will attend to such stimuli more than they will to others.
Based on the results of their own studies plus those of others, Morton and Johnson (1991) concluded that “it can now be accepted with some degree of confidence that neonates find slowly moving faces with high-contrast definition particularly attractive stimuli” (p. 172). These researchers went on to caution, however, that this does not mean newborns understand the conceptual meaning of a face, merely that they are biased to visually track face-like rather than nonface-like patterns.

Morton and Johnson (1991) developed a two-process theory for infant face preference. An initial process is accessed primarily through subcortical pathways, and this controls newborns’ tracking of faces. This system is responsible for human newborns’ preference for the human face, but because of limited sensory capabilities, infants are not able to learn about the features of faces until about 8 weeks of age. Beginning around that time, this system loses its influence over infants’ attention to faces, and the second process, which is under the control of cortical circuits, begins to take over. The functioning of this system depends on cortical maturation and experience with faces during the first 2 months of life, as infants begin to build a representation, or schema, that enables them “to discriminate the human face from other stimuli and especially from faces of other species” (Morton & Johnson, 1991, p. 178). A schema is not an exact copy of a stimulus but “a representation of an event that preserves the temporal and spatial arrangement of its distinctive elements without necessarily being isomorphic with the event” (Kagan, 1971, p. 6). This face-processing specialization is corroborated by some neuro-psychological studies that, through measuring scalp-recorded brain electric potentials (event-related potentials, ERPs) (Halit, de Haan, & Johnson, 2003) or performing positron emission tomography (PET) scans (Tzourio-Mazoyer et al., 2002), suggested that the first signs of cortical specialization for faces can be observed in 2- to-3-month-olds.

More recently, researchers have begun to investigate at what age infants detect and attend to faces within complex visual displays (Di Giorgio et al., 2012; Frank, Amso, & Johnson, 2014). Much of this research is based on L. B. Cohen’s (1972) proposal that infant attention develops as two separate processes: an attention-getting process and an attention-holding process. In these experiments, infants and adults are shown a series of dynamic (that is, moving) or static visual displays featuring a target face among a half dozen or so distractor objects. Eye-tracking devices are attached to the subjects to determine

**FIGURE 4.7** Newborn eye and head turns in following different stimuli.

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how quickly and how often they orient toward faces (that is, Cohen’s attention-getting process) and how long faces retain their attention (that is, the attention-holding process). Using this method, Elisa Di Giorgio and her colleagues (2012) showed that adults made more initial fixations (were faster) to orient toward faces than 3- and 6-month-old infants. However, 6-month-olds performed similarly to adults in how frequently they looked at faces and for how long. Three-month-olds did not look longer or more often at faces compared with other objects. Other studies confirm that 3-month-olds do not prefer faces in either dynamic displays or static stimulus arrays but that children 6 months and older show a clear face preference (Gliga et al., 2009; Gluckman & Johnson, 2013).

How do we reconcile 3-month-olds’ apparent lack of interest in faces in these visual-search paradigms with infants’ bias for faces in the preferential looking task? One interpretation may be that young babies have a weak ability to inhibit attention toward salient background information. Therefore, in preferential looking tasks, where the context in which stimuli are displayed is simple (a face and a nonface stimulus), 3-month-olds demonstrate a bias for faces because the amount of distracting stimuli is limited. In contrast, when faces are embedded in complex displays, infants may find it difficult to inhibit attention to distracting background stimuli, failing to promptly detect and privilege the face stimulus (Di Giorgio et al., 2012). Attentional control develops throughout the first year of life and is undoubtedly not mature at 3 months of age (M. H. Johnson, Posner, & Rothbart, 1991).

Michael Frank and colleagues (2009) proposed another possible interpretation, one consistent with the Goldilocks effect introduced earlier. They have shown that 3-month-olds’ visual search patterns are best predicted by the salient low-level characteristics of the stimuli presented rather than by any particular type of stimuli, such as a face (see also Easterbrook et al., 1999). Therefore, it could be that it is harder for younger babies to detect a complex visual stimulus composed of different features, such as a human face, among other complex and novel visual stimuli as distractors. Consistent with this proposal, Frank et al. (2014) found a relationship between infants’ attentional abilities in general and their attention to faces in particular; infants showing weaker attentional abilities looked less at faces, and this correlation was strongest in 3-month-old participants, mediating (partially accounting for) the relationship between age and face looking. Taken together, these findings suggest that even though neonates may often look at face-like images over other visual stimuli in forced-choice paradigms, infants’ attention to faces in complex displays that more closely resemble the input in “the real world” increases considerably over the first year.

Some evidence suggests, however, that even newborns might be able to make discriminations among individual faces, looking longer at faces of their mothers than at those of other women, for example (Bushnell, Sai, & Mullin, 1989). In related research, Gail Walton and her colleagues (1992) reported that 12- to 36-hour-old infants would vary their rate of sucking more to see a picture of their mother’s face than that of another woman. This suggests not only that newborns can tell the difference between faces and nonfaces but also that they learn a preference for their mothers’ faces shortly after birth. This early developing ability to prefer familiar faces may be evolutionarily quite old. Similar patterns have been reported for an infant gibbon (a lesser ape), which displayed a preference for looking at faces in general, and at familiar faces specifically, by 4 weeks of age (Myowa-Yamakoshi & Tomonaga, 2001).
In addition to preferring familiar faces, another quality seems to drive infants’ perception—specifically, infants show a bias toward faces that adults classify as being attractive. For example, Judith Langlois and her colleagues (1987) asked college men and women to judge the attractiveness of adult Caucasian women from photographs. From these ratings, photographs of eight attractive and eight less attractive faces were selected, although the distribution of attractiveness was relatively normal (that is, there were no extremely attractive or unattractive faces). The photographs were selected so that all women had neutral expressions, had medium to dark hair, and did not wear glasses. In one part of the study, 2- to 3-month-old and 6- to 8-month-old infants were shown pairs of faces from the selected photographs that varied in attractiveness (one more attractive and one less attractive), and their looking time was measured. Both the younger and older infants spent significantly more time looking at the more attractive faces than at the less attractive faces, with approximately two thirds of the infants showing a bias for the more attractive faces. Furthermore, the bias for the more attractive faces was unrelated to how attractive an infant’s mother was judged to be. More recent research has shown that this bias toward attractive faces is found even in newborns (Slater et al., 1998). Other research has shown that this bias extends across sex, race, and age of the modeled face: Six-month-olds consistently show a bias for attractive faces of both men and women, of both Black and White adult females, and of 3-month-old infants, despite the fact that the infants had little or no experience with some of these classes of faces (Langlois et al., 1991).

One possible explanation for these findings is that attractive faces have more of the physical stimulus characteristics that draw infant attention than do unattractive faces. For example, attractive faces might be more curvilinear, concentric, and vertically symmetrical than unattractive faces (see earlier discussion). From this perspective, infants’ bias for faces is simply a by-product of their bias for many of the physical features that happen to be characteristic of faces. Facial symmetry may be the most important factor here, for it is perhaps the single most potent determinate of attractiveness in adults (Gangestad & Thornhill, 1997). Likewise, a recent study independently manipulated the symmetry, averageness, and sexual dimorphism (how feminine or masculine a face is) of pictures of adult faces and found that infants between 12 and 24 months old looked longer at symmetrical than asymmetrical faces as well as feminine faces (Griffey & Little, 2014). Evolutionary psychologists have indicated that symmetry is a sign of physical health (Gangestad & Thornhill, 1997) and of psychological health (Shackelford & Larsen, 1997), making it possible that a preference for facial symmetry when selecting mates may have been selected for in evolution. Although mate selection is not on the minds of infants, the bias may be a general one, which is weak early in life but becomes stronger with experience. However, evidence suggesting that the bias for attractive faces involves more than just symmetry comes from work with newborns, who displayed a bias for (that is, looked longer at) upright attractive faces versus less attractive faces but not for the same faces when presented upside down (Slater et al., 2000). Moreover, infants also show a preference for more attractive faces versus less attractive faces of cats and tigers (as judged by an independent sample of adults), suggesting that this preference is not specific to human faces (Quinn et al., 2008).
The face is a complicated stimulus with many defining features, but one that has attracted much attention (from both infants and researchers) is the eyes. For example, newborns prefer to look at faces with eyes opened (Batki et al., 2000), and mutual gaze (eye contact between two people) plays a critical role in social interaction. Research has shown that even newborns are sensitive to eye gaze and are more attentive to faces that are gazing at them than to faces with eyes averted (Farroni et al., 2002). For instance, Teresa Farroni and her colleagues (2002) sat infants between 24 and 120 hours old in front of two photographs of the same female face. One face had a direct gaze, whereas the other face had its eyes averted to either the right (for about half of the babies) or to the left (for the other half). Figure 4.8 shows an example of the type of faces babies saw. A flashing light attracted infants’ attention, and then the two pictures were presented, side by side. Farroni and her colleagues reported that the newborns were more likely to orient toward the gazing face and spent significantly more time looking at the face with the direct gaze than at the picture with the averted eyes. A follow-up experiment with 4-month-olds demonstrated that infants showed enhanced neural processing, as indicated by patterns of brain activity (event-related potentials from EEGs) when they viewed faces looking directly at them as opposed to looking at faces with averted gazes. Farroni and her colleagues (2002) concluded that infants’ preference for direct gaze “is probably a result of a fast and approximate analysis of the visual input, dedicated to find socially relevant stimuli for further processing” (p. 9604).

Other research has shown that even newborns pay special attention to the eyes. For example, researchers showed newborns right-side-up and upside-down faces that were partially occluded, so that some faces showed the eyes whereas the eyes were hidden for others (Gava et al., 2008; see Figure 4.9). When babies could see the eyes, they looked longer at the right-side-up versus the upside-down faces, a pattern also shown by older infants and adults. They showed no preference, however, for either the right-side-up or upside-down face when the eyes were covered.

Research from a variety of perspectives using a variety of methodologies has illustrated that infants, from birth, are oriented toward faces, or face-like stimuli. This makes sense from an evolutionary perspective; it is also consistent with the speculation of Fantz (1961), who wrote more than 50 years ago that infants’ preferences for face-like patterns may “play an important role in the development of behavior by focusing attention to stimuli that will later have adaptive significance” (p. 72).
FIGURE 4.9 Using a visual preference paradigm, Gava et al. (2008) found that newborns who could see the eyes of a person showed a stronger preference toward the right-side-up (versus the upside-down) face, as is typically found in research using faces without occlusions. In contrast, newborns showed no preference for either the upside-down or right-side-up faces in the condition in which the eyes were covered.

- During the first month of life, infants tend to direct their attention to the outside of a figure, which is referred to as the externality effect.
- Among the physical characteristics of a stimulus that attracts infants’ visual attention are movement, contour and contrast, certain levels of complexity, vertical symmetry, and curvature.
- Beginning around 2 months of age, infants’ attention is increasingly influenced by psychological factors, such as the familiarity or novelty of a stimulus.
- Infants form long-term sensory representations, or schemas. Gibson proposed the differentiation theory to explain infants’ preferences for novel stimuli, stating that stimuli that are moderately discrepant from a previously acquired schema are most likely to be attended to. Aslin has described a similar phenomenon as the Goldilocks effect.
- Starting at a young age, infants develop a bias toward attending to the human face and look longer at attractive compared to less attractive faces. The eyes in particular are important in processing faces.

Ask Yourself . . .

5. What visual preferences, or perceptual biases, have been found in infancy? How are these preferences explained from an evolutionary perspective?
6. How have differentiation theory and the Goldilocks effect been used to explain infants’ biases toward novel and familiar stimuli?
7. What are the major milestones in the development of face processing?

AUDITORY DEVELOPMENT

Hearing is functional before birth, so infants are born with some auditory experience, notably the voice of their mother but also the sounds one would
hear when living inside the body of another person (the heartbeat, for instance). Despite this early experience, newborns are often described as being a bit “hard of hearing” (Trehub & Schellenberg, 1995). Their audition improves substantially over the first year of life, but their hearing will not be adultlike until about 10 years of age (Saffran, Werker, & Werner, 2006). To hear a sound clearly, newborns require that sound to be about 15 decibels louder than adults need. (A decibel is a measure of sound intensity. For example, a typical conversation is about 60 decibels, a train about 90 decibels, and conversation in a library about 30 decibels.) At birth, babies are relatively good at localizing the source of a sound, as reflected, for example, by turning their heads toward a sound, and this ability improves markedly by the end of the first year (S. P. Johnson, Hannon, & Amso, 2005; Morrongiello et al., 1994).

As with vision, infants enter the world with some auditory biases. For example, infants appear to be more sensitive to high-frequency than to low-frequency tones (Saffran et al., 2006), and this might explain their preference for the voices of women (Jusczyk, 1997). As with smell, infants less than 1 week old have been shown to recognize their mothers’ voices (DeCasper & Fifer, 1980). For example, Anthony DeCasper and William Fifer (1980) measured the rate at which 1- to 3-day-old infants sucked on a pacifier. They then conditioned the babies to alter their sucking rate (faster for half of the babies and slower for the other half) to the tape-recorded voices of their mothers and of an unfamiliar woman. DeCasper and Fifer reported that these young infants varied their sucking rates to hear their mothers’ voices, indicating not only that they could discriminate the voices of their mothers from those of other women but that they also acquired a distinct preference for the voices of their mothers in a matter of days.

We noted earlier that infants who heard stories being read to them by their mothers during the last 6 weeks of pregnancy were able to discriminate between that story and another and preferred the one their mother had read to them (DeCasper & Spence, 1986). The findings of DeCasper and his colleagues indicate not only that the auditory system in newborns is working well but also that babies are learning some things about the outside world while still in utero. Moreover, subsequent research following the same design as that of DeCasper and Spence has found changes in heart rate to familiar and novel passages among third-trimester fetuses, unambiguously indicating that learning occurs before birth (DeCasper et al., 1994).

We’d like to revisit the Goldilocks effect and how it applies to auditory processing in infants (for a review, see Aslin, 2014). As with visual perception, a substantial amount of research indicates that infants actively allocate attention to auditory information that is sufficiently novel from—but also sufficiently related to—their existing knowledge (e.g., Gerken, Balcomb, & Minton, 2011; Spence, 1996). In one recent study, Celeste Kidd, Steven Piantadosi, and Richard Aslin (2014) exposed 7- to 8-month-old infants to sound sequences that were designed to vary in terms of how predictable they were. For instance, some events in the sequence were highly predictable (for instance, a flute note continues to occur after 20 consecutive flute note sounds) and some were less predictable (a train whistle occurs after 10 consecutive flute notes, for instance). In addition, some sequences contained more of these predictable events than others. Kidd and her colleagues measured the point at which infants terminated their attention while listening to each of these sequences. Based on their manipulation of these stimuli, the researchers developed a model that predicts,
on an event-by-event basis, what infants should expect and how they might update their expectations based on experience with the auditory stimuli. For instance, as shown in Figure 4.10, at the beginning of a trial, infants have no reason to expect anything other than that all sounds will be presented equally. However, as a sequence progresses and they detect patterns in the sounds being played, they may alter their expectations to accommodate these patterns. The Goldilocks hypothesis holds that infants should terminate their attention to sound events that are expected but should continue allocating attention to events that have only moderate probability. Likewise, if an event is completely unexpected (exposure to a door closing sound, or Sound C in Figure 4.10), infants may perceive this as overly complex and terminate their attention at this point.

Kidd et al. (2014) used two types of models to determine the predictability or complexity of each event in the auditory sequence. The non-transitional model treated each event as statistically independent, whereas the transitional model tracked the probability that one type of event (for example, a train whistle) follows another type of event (for example, a flute note). The results of Kidd et al. demonstrated that infants adopted the Goldilocks pattern; infants were 1.15 times more likely to terminate attention to sounds in the sequences that were very low or very high in complexity (that is, very predictable or very surprising). Interestingly, this pattern was best approximated by the transitional model, suggesting that attention to auditory stimuli relies more heavily on temporal order and sequence than absolute probability. Tracking the transitional probabilities of auditory stimuli may be important for developing expectations about the auditory world, particularly in language learning, where word meaning is based on sequences of sounds rather than single events.

**FIGURE 4.10** Schematic showing an example sound sequence used by Kidd et al. (2014) and how the infant may combine heard sounds with prior expectations to form new probabilistic expectations about upcoming events (that is, the updated belief). The degree of complexity of the next sound is based on these updated beliefs, and the Goldilocks hypothesis predicts that infants will stop allocating attention at the point when the sequence becomes overly simple (that is, provides no new information) or overly complex (that is, is unexpected).

Speech Perception

One particularly interesting aspect of infant auditory perception is the extent to which it is attuned to language. For example, at birth, babies prefer to listen to language relative to comparably complex nonlanguage sounds. This suggests that infants begin life with a bias for listening to speech, thus giving them a leg up on acquiring language (Vouloumanos & Werker, 2007).
fact, recent research has shown that the amount of time infants spend listening to speech versus nonspeech in a preferential listening procedure predicts expressive vocabulary at 18 months (Vouloumanos & Curtin, 2014).

The basic units of speech are called phonemes, and evidence indicates that infants come into the world with the ability to perceive most, if not all, of the phonemes found in all human languages (see Aslin, Jusczyk, & Pisoni, 1998; Tsao, Liu, & Kuhl, 2004), suggesting substantial biological preparation for infants to learn language. This phenomenon caused Patricia Kuhl (2007) to describe young infants as “citizens of the world,” in that they seem equally ready and able to acquire any of the world’s 6,000 or so languages.

Like colors, phonemes (such as \textit{ba} and \textit{pa}) can be arranged on continua, with gradual changes between them. For example, there is a range of sounds that we hear as \textit{pa} and another range that we hear as \textit{ba}. Despite this continuum, we categorize phonemes into distinct groups. For example, we tend to hear either a \textit{pa} sound or a \textit{ba} sound, and not some hybrid of the two of them. And most of us agree on the point at which \textit{ba} ends and \textit{pa} begins, just like we agree on the division between orange and red. The gradual changes in phonemes (and in colors) are considered to be physical, and the dichotomies we perceive are considered to be perceptual.

In a classic study, Peter Eimas and his colleagues (1971) presented 1-month-old infants with one physical example of the \textit{ba}/\textit{pa} continuum until they had decreased the rate at which they sucked on a pacifier (habituation). The researchers then replaced the phoneme with another example along the \textit{ba}/\textit{pa} continuum. If the infants perceive the new sound as being from the same phonemic category as the previous sound (both \textit{ba}, for instance), then they should continue to habituate (that is, decrease their sucking). This is because even though the sound is physically different from the one they heard before, it is just another example of the sound they had just heard repeatedly (that is, just another \textit{ba}). If, however, they recognize this new sound as being from a different phonemic category (a \textit{pa} rather than a \textit{ba}, for example), they should increase their sucking rate (dishabituation). Using this technique, Eimas and his colleagues found that very young infants, like their parents and older siblings who already possess language, can categorize phonemes. They hear either \textit{ba} or \textit{pa}, and the dividing line they make between the two is the same as older members of their species make.

Other studies have used reinforcement techniques to assess infants’ abilities to discriminate among phonemes. For example, G. Cameron Marean, Lynne Werner, and Patricia Kuhl (1992) used the activation of a mechanical toy to reinforce 2-, 3-, and 6-month-old infants for turning their heads when they heard a change from one vowel sound to another (either \textit{a} to \textit{i} or vice versa). This technique showed that even 2-month-olds were able to make the discrimination, despite changes in other auditory characteristics (that is, in the voice of the individual speaking).

Speech perception is more than the ability to detect phonemes, of course. It involves the discrimination of individual words. And perhaps the word that infants hear most frequently is their own name. Denise Mandel, Peter Jusczyk, and David Pisoni (1995) asked at what age can infants recognize the sound of their own name? They used a reinforcement technique (infants turned their heads to hear a name spoken, either their own or one of three other names) to test this. Infants at 4.5 months of age spent
more time listening to their own names than to other names, regardless of whether the other names had the same stress pattern as their own (for example, Johnny versus Abby) or a different stress pattern (for example, Johnny versus Elaine). These findings indicate that infants are able to recognize frequently heard sound patterns at least by 4.5 months of age. In Chapter 9, we discuss research on how infants learn to parse out other words from the speech stream.

Music Perception

Although humans are especially prepared to process language, we also seem to be well prepared to process music. For example, some evidence indicates that infants can imitate the pitch, loudness, melodic contour, and rhythm of their mothers’ songs. Other research shows that song (even when performed by an untrained singer) is just as effective at eliciting 11-month-old infants’ attention as speech (Costa-Giomi & Ilari, 2014). Moreover, there are specific types of brain damage that affect musical abilities, suggesting that the ability to perceive and produce music is rooted in evolution and biology (see Gardner, 1983).

Many aspects of music perception appear to be adultlike very early in infancy (see Trehub, 2003, for a review). For example, babies seem to respond to changes in melody, rhythmic pattern, and redundancy much the same way that adults do and appear able to distinguish “good” from “bad” melodies (see Schellenberg & Trehub, 1999; Trehub, Trainor, & Unyk, 1993). Examples of telling the difference between “good” (regular or natural) musical patterns and “bad” (irregular or unnatural) musical patterns are particularly impressive given the diversity of human musical systems. Carol Krumhansl and Peter Jusczyk (1990) demonstrated this by having 4.5- and 6-month-old infants listen to segments of Mozart minuets. Some of the segments had pauses inserted at the end of each musical phrase (natural), whereas other segments had pauses inserted in the middle of phrases (unnatural). Infants learned to control which music they heard—natural or unnatural—by turning their heads in the direction of the speaker playing the music they preferred. Overall, infants spent more time listening to the natural than to the unnatural versions. Of the 6-month-olds, 22 of 24 showed this pattern; of the 4.5-month-olds, 20 of 24 showed this pattern. Other research has found that infants as young as 6 months prefer tones related by simple ratios (what most adults consider to be consonant, or pleasant sounding) over dissonant sounds (as found in atonal music) (Schellenberg & Trehub, 1996; Virtala et al., 2013). Newborns also seem to know the difference between major (happily sounding) and minor (sad-sounding) chords, as indicated by event-related potential readings (Virtala et al., 2013). Other research has shown that by 4 months of age, infants display a preference for the music of their own culture relative to that of another culture (Soley & Hannon, 2010). Given these infants’ lack of musical experience, the results of these experiments suggest that music appreciation might not require a college class to attain and, in fact, might be a basic characteristic of the human nervous system.

Some of the most compelling evidence that musical perception is inherent to the newborn comes from research using functional MRI (fMRI) to measure brain activity of 1- to 3-day-old newborns as they listen to Western tonal music (Perani et al., 2010). In adults, the right hemisphere shows a specialization for processing musical sequences. When neonates listened
to Western tonal music, they showed activation of the primary and higher auditory cortex in the right hemisphere as well. When altered excerpts of these sequences were played, which included changes in the tonal key or continued dissonance, activation reduced in infants’ right auditory cortex and emerged in the left inferior frontal auditory cortex and limbic structures. These findings suggest that the hemispheric specialization for music observed in adults is the result of neurobiological constraints present in neonates. In addition, this neural architecture is sensitive to changes in tonal key and differences in consonance and dissonance in the first postnatal hours.

Numerous hypotheses have been advanced about the evolutionary origins of music, dating back at least to Darwin (1871). One hypothesis is that music played a social function, stemming from early humans’ ability to synchronize body movements to an external beat. In support of this idea, Sebastian Kirschner and Michael Tomasello (2009) reported that 2.5-year-old children were better able to synchronize their body movements to a beat in a social situation (a person drumming to create the beat) versus a nonsocial situation (with the drumming done by a machine). Another proposal for the origins of music looks to early mother-infant interaction. The lullabies that mothers around the world sing to their babies are performed in an expressive and highly ritualized manner (see Masataka, 1999; Trainor, 1996) and serve to regulate infants’ attention and emotion (see Trehub, 2003). In fact, although infants are highly attentive to infant-directed speech—the sing-songy and expressive style that mothers around the world use when talking to their babies (see Chapter 9)—they are even more attentive to their mothers’ singing (Trehub & Nakata, 2001–2002).

Section Review

Infants begin learning about the world via auditory input while still in the womb. They are born with a preference for high-pitch voices and speech as well as music.

- As with visual information, young infants learn auditory patterns and develop expectations based on these experiences. Based on these expectations, infants attend to auditory information that is neither too simple nor too complex, and this is referred to as the Goldilocks effect.
- Young infants can discriminate among phonemes and categorize language sounds much as adults do, and they appear to be biologically prepared to perceive music.

Ask Yourself . . .

8. What are the major milestones in the development of speech processing and music? What does the development of these abilities have in common with face processing, if anything?

Combining Senses

Although we often think of each sense as being distinct from all others, as adults we do a great deal of coordinating information between senses. We direct our vision to a loud noise, and we can identify our slippers by touch alone when we are awakened in the middle of the night by a barking dog outside our window. In fact, the environment for adults is “intrinsically multimodal” (Bahrick, Lickliter, & Flom, 2004). To what extent is such sensory integration available to infants, and how can we interpret such integration when we observe it?
Intersensory Integration

Intersensory integration refers to the coordination of information from two or more sensory modalities. At one level, intersensory integration is present at birth. Newborns move their heads and eyes in the direction of a sound, as if they wish to see what all the noise is about. In a series of experiments examining the effects of sound on visual scanning in newborns, Morton Mendelson and Marshall Haith (1976) found that the presence of sound increased infants’ visual attentiveness. The researchers suggested that this response to sound increases the likelihood that infants will discover something to look at.

Elizabeth Spelke (1976) provided an interesting demonstration of intersensory integration in infants. Spelke showed 4-month-old infants two films on side-by-side screens. On one screen was a film of a woman playing peek-a-boo; on the other screen was a hand holding a stick and striking a block of wood. A single sound track was played, corresponding either to the peek-a-boo or the drumming. The babies figured out which sound track went with which screen, devoting more looking time to the screen that matched the sound. That is, these 4-month-old infants realized that certain sound sequences go with certain visual displays, and they visually attended to those displays that provided such a match (see also Bahrick, 2002).

In somewhat related work, Lorraine Bahrick and John Watson (1985) investigated the ability of 5-month-olds to integrate proprioceptive (relating to perception of body movements) and visual information. The babies were seated in infant seats equipped with a type of tray that prevented them from seeing their legs. Two video screens were placed in front of the infants. One screen displayed the infant’s own legs; that is, the picture was transmitted live. The other screen displayed a film of the legs of another infant (or in one experiment, the same infant’s legs from a session recorded earlier). Thus, for one display (the contingent display), the movement of infants’ legs was contemporaneous with their actual movement, whereas for the other display (the noncontingent display), the movement of legs was independent of the infants’ current activity. Bahrick and Watson reasoned that if infants are able to integrate proprioception (as reflected by their own leg movements) and vision, they should be able to discriminate between the two films and spend more time looking at one than at the other. This was their finding. In three experiments, 5-month-olds spent, on average, 67% of their time looking at the noncontingent display. Presumably, the lack of contingency between their leg movements and those seen on the video produced some discrepancy, and this resulted in increased attention to the noncontingent display. In another experiment, Bahrick and Watson (1985) tested 3-month-olds and found no overall preference for either the contingent or the noncontingent display. They concluded that proprioceptive-visual integration is well established by 5 months and that the ability to detect the congruence between one’s movements and their visual representation plays a fundamental role in an infant’s perception of self, possibly underlying the development of visual self-recognition (discussed in Chapter 10). Other researchers, using a similar design that varied the spatial orientation of the images that infants saw, report that even 3-month-olds can detect the congruence between their actual leg movements and a video image of those movements (Rochat & Morgan, 1995), suggesting that this might be an early developing ability (for further review, see Zwicker, Moore, & Povinelli, 2012).
Is intersensory integration present at birth? Although research clearly indicates that intersensory abilities improve with age (see Lewkowicz & Lickliter, 2013, for a review), even newborns are capable of recognizing the equivalence between stimuli in two different modalities (a bright light and loud sound, for instance; Lewkowicz & Turkewitz, 1980) and prove capable of matching monkey vocalizations with facial gestures (Lewkowicz, Leo, & Simion, 2010). Yet this does not mean that such abilities are innate, at least not in the way that term is typically used. The developmental systems approach, introduced in Chapter 2, argues that all traits develop as a result of the bidirectional interaction between different levels of organization within the organism and that normal prenatal experiences are crucial in determining species-typical patterns of development. Such arguments are also applied to intersensory integration in infants (Lewkowicz & Lickliter, 2013). Perceptual experience begins before birth, and the specific experiences a fetus or an embryo receives can alter its development, including the ability to integrate information between senses. For example, we discussed in Chapter 2 research by Robert Lickliter (1990) in which exposure to light before hatching augmented bobwhite quails’ subsequent visual abilities but was detrimental to some important auditory skills (identifying their species’ call). Although space limitations prevent us from discussing these ideas in any detail, what’s important to keep in mind when seemingly advanced abilities are observed in very young infants is that these skills are not preformed and functioning without the benefit of prior experience. Rather, such skills are constructed from the interaction of genes and environment, broadly defined, which begins prenatally and continues throughout life.

### Intersensory Matching

A seemingly more complex intermodal feat concerns intersensory matching (or cross-modal matching). In intersensory matching, a child must be able to recognize an object initially inspected in one modality (touch, for example) through another modality (vision, for example). Susan Rose and her colleagues (1981) showed that 6-month-old babies can perform visual-tactual integration. The infants were presented an object (either through touch alone or vision alone) for 60 seconds (familiarization phase) and later presented a small set of objects through the alternative mode (transfer phase). The researchers reported that the infants spent more time during the transfer phase exploring the novel objects (by manipulating or gazing at them) than exploring the familiar ones. That is, the babies showed dishabituation by examining the novel stimuli more than the familiar stimuli, even though familiarization was done in a different sensory modality. Other studies using similar methods have demonstrated intersensory matching for 4- to 6-month-old infants (Streri & Spelke, 1989).

Substantial research has been done examining infants’ developing ability to integrate sound patterns to the face patterns and movements that produce them. For instance, 4- to 5-month-old infants can associate lips movements congruent with the speech they are hearing (Spelke & Cortelyou, 1981) or with the utterance of specific phonemes, like i and a (Kuhl & Meltzoff, 1982). This early developing ability to associate auditory and visual information becomes more specific with experience. For instance, although 9-month-old infants can interconnect females’ voices and faces, they can’t reliably associate male voices and faces until about 18 months (Poulin-Dubois et al., 1994). This superiority of matching the
voices and faces of females likely results from babies having more experience interacting with women than with men (Ramsey-Rennels & Langlois, 2006).

Section Review

- **Intersensory integration** refers to the coordination of information from two or more sensory modalities and may be present at birth or shortly thereafter.
- **Intersensory (or cross-modal) matching** refers to the ability to recognize a stimulus initially inspected in one modality (vision, for example) through another modality (touch, for example).

**Ask Yourself . . .**

9. What are the major milestones in the development of intersensory integration? How do we know that experience is important for normal development to occur?

**PERCEPTUAL NARROWING**

An infant is born a “citizen of the world,” not knowing the particular culture, language, or perhaps even primate taxa in which he or she will develop. As such, newborns’ perceptual abilities are broadly tuned to a wide variety of stimuli. However, there is growing evidence that perception narrows across many domains within the first year, including those related to facial and speech perception. This phenomenon, referred to as **perceptual narrowing**, is the process by which infants use environmental experience to become specialists in perceiving stimuli relevant to their species and culture. As a result, however, infants become relatively less effective at perceiving some things with which they have less experience (Lewkowicz & Ghazanfar, 2009; Pascalis et al., 2014). This developmental process is the result of neuroplasticity, discussed in Chapter 2.

Human infants are born with the ability to process a wide variety of stimuli; however, as neural pathways are more consistently used they are strengthened (and those used less frequently are weakened), resulting in a more selective perception of information that is socioculturally relevant.

**Perceptual Narrowing for Facial Discrimination**

Earlier in this chapter, we discussed research that showed babies initially have a weak bias to attend to faces, which becomes stronger with age and experience. For example, from about 3 to 9 months, infants process upright faces more efficiently than inverted faces, revealing what appears to be an early developing appreciation of what the proper orientation of faces is “supposed” to be (Bhatt et al., 2005; de Haan, Oliver, & Johnson, 1998). By 9 months, perception has further narrowed such that, like adults, 9-month-olds show this bias only for human faces, whereas 6-month-olds show it for both human and monkey faces (Pascalis, de Haan, & Nelson, 2002). This pattern suggests that the brains of infants are biased to process right-side-up faces, perhaps the most important stimulus in the world of a young animal highly dependent on care from others. However, the fact that 6-month-olds do not give special privilege to human faces suggests that brain processing of faces becomes more specialized with age and experience. According to Olivier Pascalis and his colleagues (2002), “The ability to perceive faces narrows with development, due in large
measure to the cortical specialization that occurs with experience viewing faces. In this view, the sensitivity of the face recognition system to differences in identity among the faces of one’s own species will increase with age and with experience in processing those faces” (p. 1321).

As we noted elsewhere in the text, it takes time and experience for this special status for faces to develop. This can be seen in how infants process male versus female faces. For instance, 3- and 4-month-old infants can discriminate more easily between female than between male faces, and they generally prefer to look at female faces, with the exception of when the father is an infant’s primary caretaker (Quinn et al., 2002; see also Rennels et al., 2016). Infants’ increasing specialization at making distinctions between the faces of men and women and between different species (for example, monkeys versus humans; see de Haan et al., 1998) clearly illustrates the importance of experience in processing this most important of social stimuli (Ramsey-Rennels & Langlois, 2006; Turati, 2004). Still not convinced that experience is important in shaping these specializations? Consider that the ability to continue discriminating monkey faces is preserved in 9-month-old humans who were repeatedly exposed to monkey faces starting at 6 months (Pascalis et al., 2005; see also Fair et al., 2012).

Infants not only become “specialized” in discriminating among faces of different species and between men and women, they also develop an increasing ability to discriminate between faces of their own race relative to those of other races. This is termed the other-race effect. For instance, infants are shown faces from a particular ethnic group until they habituate; later, they are shown photos of people from their own ethnic group and others (for example, Caucasian versus Asian). In studies by David Kelly and his colleagues (2007, 2009) with both British and Chinese infants, 3-month-olds showed no other-race effect. They were equally skilled at recognizing faces from all ethnicities tested (Caucasian, Chinese, and African, as well as Middle Eastern for the British infants). However, by 6 months of age, infants could only recognize faces from their own race plus one other (Chinese and Caucasian), and by 9 months, infants were only able to recognize faces in their own race (Chinese or Caucasian). This phenomenon is not an indication of implicit racism in infancy; rather, it reflects the role of familiarity in shaping infants’ perceptual abilities (see Anzures et al., 2013). However, infants retain the neural plasticity to modify their face-discrimination abilities. For example, in one study 8- and 10-month-old Caucasian infants were exposed to photographs of Asian female faces for 3 weeks and were later able to discriminate among Asian as well as Caucasian faces (Anzures et al., 2012).

Perceptual Narrowing in Speech Perception

Just as infants’ preference for faces becomes species-specific over time, so does their preference for speech narrow within the first 3 months of life. As we described earlier, human neonates prefer listening to speech compared to many
nonspeech sounds, suggesting that humans are born with a bias for speech. However, as Athena Vouloumanos and colleagues (2010) demonstrated, this preference is not specific to human vocalizations at birth and minimally includes speech and monkey vocalizations. Vouloumanos and her colleagues (2010) presented thirty neonates and sixteen 3-month-olds with nonsense speech and rhesus monkey vocalizations. Neonates showed no preference for speech over rhesus vocalizations but showed a preference for both these sounds over synthetic sounds. In contrast, 3-month-olds preferred speech to rhesus vocalizations. These findings parallel results on infant face perception and suggest that a species-specific preference for speech develops across the first 3 months.

How else might infants’ speech perception narrow early on? If, as we described earlier, infants can discriminate basic phonemes shortly after birth, how is it they acquire the language sounds peculiar to their mother tongue? English-speaking adults have a difficult time discriminating phonetic contrasts that occur in Czech but not in English, for example. Yet babies from English-speaking homes have little difficulty with these contrasts, suggesting that they were born with the ability (Trehub, 1976). Other studies have similarly shown that infants can make discriminations among speech sounds that are not found in their mother tongues and that their parents cannot make (Kuhl et al., 2006; Saffran et al., 2006). Before about 6 months of age, infants can discriminate all consonant contrasts in native and nonnative languages, but by 10 to 12 months, perception becomes more adultlike, with infants losing the ability to discriminate nonnative contrasts but maintaining the distinction between those that are native. For example, Rebecca Eilers and her colleagues (1979) reported that 6- to 8-month-old infants from English-speaking homes were unable to discriminate some phonetic contrasts that are found in Spanish but not in English. Babies from homes where Spanish was spoken, however, had no trouble with such contrasts. This change in infants’ sensitivity may develop earlier, as young as 6 months, for vowels (Kuhl et al., 1992). What these and other data suggest is that babies can make some sound discriminations that adult speakers of their language communities cannot make; with time, babies lose the ability to make these contrasts because they rarely hear them.

At the same time that infants are losing their abilities to discriminate among “foreign” phonemes, they are becoming more sensitive to the speech regularities in the language they hear every day. For instance, they are able to make increasingly fine discriminations between the phonemes in their mother tongue (Kuhl et al., 2006). They also become increasingly able to recognize the stress patterns of their language (such as the first syllable of two-syllable words stressed in English, as in table and carpet), to identify some typical phoneme combinations and syllables that occur more often in their language, and to pay attention to the pauses between words (Aslin, Saffran, & Newport, 1998).

Other research has shown that young infants are able to differentiate sentences uttered in their native language versus those in a foreign language on the basis of vision alone, but as with sound discrimination, they lose this ability over time (Weikum et al., 2007). For instance, 4-, 6-, and 8-month-old infants watched silent video clips of a woman speaking sentences either in the infants’ native language (English) or in a foreign language (French). After infants’ looking time to the videos decreased (that is, after habituating), some were shown videos of a woman speaking the other language (for
instance, French if infants had been habituated to English). The 4- and 6-month-old infants increased their looking time to the new video, indicating that they could tell the difference between sentences spoken in their native versus a nonnative language by vision alone—that is, just by watching the lips of the speaker. However, 8-month-old infants continued to habituate, indicating that they could not discriminate between the two languages on the basis of vision alone. Other research has shown hearing babies similarly lose the ability to discriminate signs in American Sign Language from 12 to 14 months of age (Baker Palmer et al., 2012). These findings indicate that with experience, infants lose some of their ability to discriminate between languages on the basis of vision alone, much as they lose the ability to discriminate between sounds in nonnative languages. As children become more experienced with their native tongue, they lose some perceptual plasticity, becoming specialists in their own language.

Why should children lose this seemingly valuable ability? The flexibility to learn the sounds (or lip movements) of any possible human language would seemingly provide a great adaptive advantage, of course, but keeping this flexibility beyond a certain age likely was not adaptive in practice. Once our ancestors learned one language, there was likely little need (or opportunity) to become proficient in another. Thus, it makes more sense for the brain to dedicate neurons to processing the sounds it hears early in life. The alternative would give individuals more flexibility but likely less proficiency in perceiving or producing any one language. Infants exposed to more than one language are an interesting exception to this general rule. For instance, bilingual children are able to discriminate among a broader range of phonemes than monolingual children (see Bosch & Sebastián-Gallés, 2001; MacWhinney, 2015).

**Perceptual Narrowing and Music**

As you might be expecting by now, infants’ perception of music follows a similar trajectory as speech and facial perception; newborns can discriminate musical structures that elude their parents. By the end of the first year, however, these abilities decline to the cultural-specific structures. For example, in one study, infants and adults were played a series of notes based on Western scales and Javanese pelog scales (Lynch et al., 1990). The formal description of these two musical systems is beyond the scope of this book (and our expertise); suffice it to say that the underlying scales differ considerably (to listen to some pelog music, Google “pelog music YouTube”). Adults and 6.5-month-old infants heard well-tuned or out-of-tune patterns of both types of music and were asked to distinguish between the two. The infants, of course, weren’t asked to “tell” the difference; an operant-conditioning paradigm was used in which infants were rewarded for turning their heads toward out-of-tune series. The adults, who merely raised their hands for an out-of-tune series, were better able to distinguish between in-tune and out-of-tune patterns in the Western music than in the Javanese music, reflecting the influence of experience on their musical perception. (The adults were American, and all were familiar with the Western but not the Javanese system.) The infants, however, were equally good at distinguishing the out-of-tune series for both the Western and Javanese patterns, “suggesting that infants may be born with an equipotentiality for the perception of scales from a variety of cultures” (Lynch et al., 1990, p. 275). That is, just as children are capable
of and biologically prepared for acquiring any human language, they seem also to be prepared for acquiring any system of music.

**Perceptual Narrowing Within Intersensory Integration**

We described that infants’ abilities to discriminate between different phonemes in all the world’s languages and to differentiate between faces from other races decline with age and experience. Something similar seems to be happening for intersensory perception. For instance, 2-month-old infants will look longer at a human face that corresponds to a sound (for instance, seeing a face saying ee and hearing the sound ee) than at a face that does not correspond to a sound (for instance, a face saying ee and the sound ah), and this ability improves with age (Patterson & Werker, 2003). How general is this ability, and do children always get better at it with age? In one study, 4-, 6-, 8-, and 10-month-old infants watched the face of a monkey as it made one of two sounds, a coo or a grunt (see Photo 4.2, from Lewkowicz & Ghazanfar, 2006). Sometimes the infants heard a sound that corresponded with the face (for example, the coo face with the coo sound), and other times the sound and the face were mismatched (for example, the coo face with the grunt sound). The 4- and 6-month-old infants looked significantly longer at the faces that matched the sounds, but the 8- and 10-month-old infants did not. A later study found that even newborns looked significantly

**PHOTO 4.2** The face of a monkey making a grunt sound (A) and making a coo sound (B). Both 4- and 6-month-old infants looked longer at the face making the sound, but older infants did not.

\[\text{Grunt} \quad \text{Coo}\]

\[\text{Grunt} \quad \text{Coo}\]

\[\text{Grunt} \quad \text{Coo}\]

longer at the faces that matched the sounds (Lewkowicz et al., 2010). Much like unimodal perception of language sounds, intersensory perception also shows a narrowing of ability with age and experience. What begins as a general ability to match sounds and faces becomes specialized to the types of faces (humans) and sounds (native language) that one hears (for similar results see Pons et al., 2009; Weikum et al., 2007).

Perceptual Narrowing as an Evolved Social-Cognitive Mechanism

Perceptual narrowing has been documented for infant and young children’s processing of language, gestures (sign language), face processing, and music, as well as intersensory processing of vision and speech. Olivier Pascalis and his colleagues (2014) have proposed that this pattern of perceptual narrowing reflects an evolved mechanism that serves to foster social communication. The mechanism, they proposed, is not specific to any single cognitive ability but is common to several early developing forms of communication. Humans’ highly social nature requires that infants learn to identify and communicate effectively with others—not just other members of their own species but other members of their particular social group. Through interactions with their mothers and others during their first year of life, infants become increasingly skilled at recognizing faces, speech sounds, gestures, and even the music characteristic of their social group, while losing the ability to process faces, sounds, and gestures from other social groups. The social and survival value of the rapid development of such communication skills appear obvious.

Section Review

Human infants are born with the ability to process a wide variety of stimuli. Perceptual narrowing is a process by which infants become tuned to sociocultural relevant information as a result of experiences during the first year of life. As perception becomes specialized, infants lose the ability to distinguish stimuli with which they have less experience. This developmental process is the result of neuroplasticity.

- Over the first year, face processing becomes increasingly specialized, and infants develop an increasing ability to discriminate between faces of their own race and experience a decreasing ability to discriminate between faces of other races, termed the other-race effect.
- By 9 months of age, infants lose the ability to discriminate phonemes that do not correspond to meaningful differences in their own language and become more sensitive to the speech regularities in the language they hear every day.
- Similar narrowing is observed for music perception and intersensory perception within the first year of life.
- This process is based on experience. With continued exposure to stimuli, infants maintain the ability to discriminate.
- Perceptual narrowing may be an evolved mechanism that serves to foster social communication.

Ask Yourself . . .

10. What is meant by perceptual narrowing, and what are some evolutionary explanations for its development?
11. How does the perception of speech and faces narrow across development? Are there parallels between these processes?
12. How does experience influence perceptual narrowing?
HOW DO WE KNOW WHAT BABIES KNOW? THE VIOLATION-OF-EXPECTATION METHOD

Despite how much we have learned about infant perceptual development, we need to be cautious and not attribute too much “intelligence” to babies based on sucking rate or looking time (Haith, 1993; Hood, 2004). As evidenced by the research on perceptual narrowing that we’ve just discussed, one should not view an infant’s perceptual skills as fully developed the first time one sees them. Like most aspects of development, perceptual development is context dependent, and an infant’s response can vary substantially from one time or situation to the next. This becomes even more important when we go beyond perception and examine infant cognitive development.

As we mentioned earlier in this chapter, it is not always easy to tell when perception ends and cognition begins. Many of the feats we described in the previous sections on perception, such as discriminating between different faces, can be quite complex and perhaps better deserve the label cognition than perception. In this section, we look at what many consider to be some lower-level cognitive abilities, including infants’ understanding of objects, understanding of quantities, and abilities to form categories. Other higher-level forms of infant cognition, such as understanding social relations, memory, and problem solving, are discussed in later chapters. Before examining specific aspects of infant cognition, however, we first look at the most frequently used method for assessing aspects of infants’ cognition—the violation-of-expectation method.

In the violation-of-expectation method, an infant’s reaction to an unexpected event is used to infer what he or she knows. This method uses infants’ looking behavior, much as in the preference-for-novelty and habituation/dishabituation procedures, to assess infants’ reaction to unexpected events. The logic is simple: If infants see an event that deviates from what they expect—in other words, that violates their expectation—they should look longer at that event than at an “expected” event.

Let us provide an example from a study by Andréa Aguiar and Renée Baillargeon (1999) on the development of infants’ understanding of objects. In this study, 2.5-month-old infants watched as a toy mouse disappeared behind one screen on the right side of a display and then reappeared seconds later from behind another screen on the left side of the display without appearing in the gap between the two screens (Aguiar & Baillargeon, 1999; see Figure 4.11). Infants looked longer at the magically appearing mouse than at the “expected” event (the mouse traveling through the gap between the two screens), suggesting that they were puzzled about how the mouse could have made the trip from one side of the display to the other without passing through the middle. As you can see, the violation-of-expectation method does more than simply inform researchers that infants can tell the difference between two stimuli, and variants of this method have been frequently used to provide insights into the infant mind (see Aslin, 2007; Baillargeon, 2008; and discussion later in this chapter).

As we warned for measures of infant perception, we must be cautious and not attribute too much in the way of sophisticated cognition based on how long infants look at one event versus another. But when the looking behavior of groups of infants systematically varies between expected and unexpected events, a researcher can be confident that something is going on in
FIGURE 4.11 An example of an “impossible” occlusion event. A toy mouse disappears behind a first screen and appears later behind a second screen, without appearing in the gap between them. Infants as young as 2.5 months of age seem to realize that objects cannot disappear at one point and then magically appear at another.


the minds of babies to produce such reliable results. It’s the job of the psychologist to determine what exactly that something is.

CORE KNOWLEDGE

Infants are obviously not born as blank slates—beings with no biases simply waiting for experience to mold their minds. As we saw in the previous sections, babies enter the world, or develop shortly thereafter, with things they are biased to look at and listen to, and they are better at processing some types of information (faces, for instance) than others. Elizabeth Spelke and her colleagues (Spelke, 2000; Spelke & Kinzler, 2007), among others (for example, Baillargeon, 2008; R. Gelman & Williams, 1998), argue that babies possess core knowledge about several different domains from birth. They argue that infants are born with a small set of distinct systems of knowledge that have been shaped by natural selection over evolutionary time and upon which new and flexible skills and belief systems (such as reading, arithmetic, navigating by maps, reasoning about other people’s thoughts) are later built.

Spelke and her colleagues argue that strong evidence indicates the existence of at least three core-knowledge systems in infancy (see Table 4.1): (1) object representation, (2) knowledge of people and their actions, and (3) an ability to represent numbers, or quantities. David Geary (2005, 2007) has made a similar proposal, arguing that infants are born with a small set of skeletal competencies specialized to process information relating to the physical world (folk physics), the biological world (folk biology), and people (folk psychology; recall our discussion of Geary’s theory in Chapter 2). These skeletal abilities become fleshed out with time and experience, allowing children to deal effectively with a wide range of objects, events, and relationships as they develop. Infants thus enter the world prepared to learn and understand some things better than others, but such biases are modified, in a species-typical way, as a result of experience.

Core-knowledge systems are inferred not only by evidence from experiments with infants but also from research with nonhuman animals and
TABLE 4.1 According to the core-knowledge systems perspective, human infants are endowed with at least three core-knowledge systems to represent and make inferences about relevant aspects of their surrounding environment.

Core-knowledge system 1: Inanimate objects and their mechanical interactions
1. **Cohesion** (objects have boundaries and their components are connected to each other)
2. **Continuity** (objects move along unobstructed paths and cannot be in the same place)
3. **Contact** (one object must contact another to make it move)
4. **Number limitation** (infants cannot represent more than about three objects at a time)

Core-knowledge system 2: Persons and their actions
1. **Goal directness** (intentional human actions are directed to goals)
2. **Efficiency** (goals are achieved through the use of effective means)
3. **Contingency** (means are not applied rigidly but adjusted to the conditions found)
4. **Reciprocity** (such as turn taking in conversation)
5. **Gaze direction** (the direction of a gaze is used to interpret social and nonsocial actions)

Core-knowledge system 3: Numbers representation
1. **Abstractness** (number representations are abstract: they apply to different entities or things, from different sensory modalities, for example, a set of objects or set of sounds)
2. **Comparability and combinability** (number representations are comparable and can be combined by addition and subtraction operations)


with people from traditional cultures. For example, in some cases, evidence suggests that humans share some core abilities, such as aspects of object representation (see Dore & Dumas, 1987), basic arithmetic abilities (see discussion later in this chapter), and understanding of social partners (see Chapters 6 and 10), with other animals. However, some abilities, such as shared attention (for example, mother and infant sharing information and attention about a third object) may be unique to *Homo sapiens* (Tomasello, 2000; see Chapter 6). Evidence that humans share early developing abilities with other species, especially taxa closely related to humans, is central to a core-knowledge perspective; if we observe at least hints of these core competencies in our primate relatives, it suggests we may have also shared them with our last common ancestor and that these abilities have a long phylogenetic history. In other words, these comparative findings lend weight to the argument that humans are born prepared to process information within these core-knowledge systems as a result of millions of years of natural selection.

In this chapter, we examine some research motivated by the core-knowledge approach with respect to object representation and understanding of numbers. Research looking at infants’ and children’s folk psychology is explored in Chapters 6 and 10.
Object Representation

A basic question in infant spatial cognition concerns what they know about the nature of objects, for example, the extent to which they understand that physical objects follow the basic Newtonian laws of physics—must everything that goes up eventually come down? Infants have to recognize at least three features related to objects: (1) object constancy, (2) object cohesion and continuity, and (3) object permanence. Object constancy refers to the fact that an object does not change size or shape depending on how one views it. It may look different from a different angle, but it’s still the same size and shape. Object cohesion and continuity refers to the fact that individual objects are seen as cohesive wholes with distinct boundaries. Object permanence refers to the fact that objects are permanent in time and space, whether we are perceiving them or not; that is, objects continue to exist even if they are out of our sight. In the following sections, we discuss the development of each of these aspects of object representation.

Object Constancy

Perhaps the most basic form of spatial cognition concerns infants’ understanding of the constancy of physical objects in time and space. Object constancy refers to the knowledge that an object remains the same despite changes in how it is viewed. Consider a table, for instance. When we see the table at a certain distance, it makes a specific impression on the retinas of our eyes. As we move away from the table, that image on the back of our eyes gets smaller, but we continue to perceive the table as maintaining a constant size and shape. We don’t act as if the table is changing before our eyes; although the literal sensation changes, we maintain a perceptual constancy in our minds.

This would seem to be a very basic form of spatial cognition, and in fact, it is possessed to varying degrees even by newborns. Imagine, for example, that newborns are habituated to an object of a particular size. During test trials, the infant is then shown one of two objects: the same object presented at a different distance so as to project a different-sized retinal image or a new object of a different size but presented at a distance so that the retinal image it projects is the same size as the retinal image projected by the original habituated object (see Figure 4.12).

If infants perceive size constancy, meaning they understand that the object remains the same even

FIGURE 4.12 Size constancy experiment. After becoming used to looking at a small cube at different distances (habituation to changes in retinal image), infants are presented a second larger but more distant cube (same retinal image for both cubes). If infants pay more attention to the larger than to the smaller cube, researchers conclude that they are distinguishing the cubes on the basis of their actual, not their retinal, size. That is, infants are demonstrating size constancy.


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though the retinal image changes across space and orientation, then they should continue to habituate to the same object at a different distance, even though the actual retinal image is different. If they do not possess size constancy, however, they should dishabituate to the same object at a different distance and continue to (erroneously) habituate to the new object that produces the same retinal image. In one such study (Slater, Mattock, & Brown, 1990), newborns showed the former pattern, displaying a degree of size and shape constancy that, although not quite adultlike, indicates that human infants are well-prepared at birth for making sense of physical objects.

Despite this precocious ability, older children sometimes reveal what appears to be a surprising ignorance of size and shape constancy. For example, I (DB) recall sitting with 4-year-old Brendan, looking at planes flying overhead. “How do they get so small?” he asked. “Huh?” was probably my response, and he went on to wonder how big planes like he sees at the airport can get so tiny when they go up in the air. He seemed not to have realized that the plane stays the same size despite the vastly changing retinal image it projects as it soars away. Brendan is not unique in his confusion, for we have heard other people describe their children’s mystification of the “amazing shrinking abilities” of airplanes. (“When do we get small?” asked one preschool child of her mother on her first airplane trip. This child figured out that if the plane gets smaller, then so, too, must the people inside it.) What we seem to have here is a discrepancy between the implicit knowledge of the infant, assessed by looking-time or operant-conditioning procedures, and the explicit, verbalizable knowledge of the older child. Granted, in most of children’s everyday experiences, they behave as if objects maintain their size and shape despite changes in retinal image. Yet for extraordinary events—extraordinary in that they were unlikely to be experienced by our ancestors hundreds of thousands or even millions of years ago, such as large, rapidly moving, flying objects—the appearance of a change in size seemingly overpowers children’s intuitive knowledge of object constancy, reflecting a disconnect between what they know implicitly (without conscious awareness) and what they know explicitly (with conscious awareness).

Object Cohesion and Continuity

Another form of basic spatial cognition in infancy concerns the Gestalt concept of continuation. As mentioned earlier, object cohesion and continuity refers to the fact that individual objects are seen as cohesive wholes with distinctive boundaries. For example, Figure 4.13 shows a solid rectangle with

![FIGURE 4.13  Example of the Gestalt concept of continuation. An important acquisition in visual perception is identifying objects that appear connected, or together, visually as independent objects. A widely used stimuli has been this rectangle with two broken rods. Typically, adults infer that the rectangle is overlapped over a solid bar behind it. Four-month-old infants (and even 2-month-old infants, in some cases) infer the same, but only if both rods exhibit a continuous same-speed movement.](source: © Cengage Learning.)
bars extending from its top and bottom. Adults infer that the rectangle is occluding a solid bar. Although no solid bar is actually seen, we “fill in the gaps” or form an expectation of what is behind the box. Will infants make the same inference? How can one tell? One way is by repeatedly showing infants the stimulus until their attention to it decreases (habituation) and then showing them a picture of a solid bar in the same orientation as the partial bars in the original stimulus. If the infants increase their attention to the complete rod, they would be treating it as if it were novel, indicating that they had perceived the original rod as a disjointed object. If, however, when shown the solid bar they show little interest in it (that is, they continue to habituate), they would be treating it like an “old” stimulus, one they’ve gotten tired of looking at. But it is not literally the “same old thing.” It is a different physical stimulus. If they treat it like an old stimulus, it would be because they have inferred that the rectangle in the original stimulus was occluding a solid bar.

When doing experiments like this, how do babies respond? Infants at 4 months of age treat the solid bar as if it were an old stimulus (that is, they continue to habituate), but only for moving stimuli (as shown by the arrows in Figure 4.13) or displays in which the rod parts underwent apparent motion (sometimes referred to as phi motion; Valenza & Bulf, 2011), not for stationary stimuli (S. P. Johnson & Aslin, 1996; Kellman & Spelke, 1983). Elizabeth Spelke (1985) speculated that this is an indication that infants are born with the notion of the persistence, coherence, and unity of objects. They “know,” at some level, that objects are continuous in space. However, subsequent research indicated that 2-month-old (S. P. Johnson & Aslin, 1995) and 4-month-old (Eizenman & Bertenthal, 1998) infants will show evidence of inferring object unity in some, but not in other, situations and that newborns increase their attention to the solid bar (Slater et al., 1990), suggesting that babies are likely not born with this knowledge.

Spelke and her colleagues have conducted other studies consistent with the interpretation that infants as young as 2.5 months of age have a knowledge of the solidity and continuity of objects (the fact that a moving object continues on its path) (see Spelke & Kinzler, 2007). More recently, Renée Baillargeon and her colleagues have investigated young infants’ understanding of support (an object must be supported or it falls) (Baillargeon, Kotovsky, & Needham, 1995), collisions (an object that is hit by another object moves) (Baillargeon et al., 1995), and containment (a larger object cannot fit into a smaller object) (Aguiar & Baillargeon, 1998).

We discussed infants’ understanding that objects must travel through space to get from Point A to Point B earlier in this chapter when describing the violation-of-expectation method. As you may recall, infants as young as 2.5 months of age looked longer at an event in which an object somehow moved behind one barrier and appeared seconds later from behind another without traversing the area in between (Aguiar & Baillargeon, 1999). The concept of collision seems to develop about the same time. For example, 2.5-month-old infants increased their looking time when a toy bug on wheels remained stationary after being hit by a cylinder rolling down a ramp or, conversely, when the bug moved in the absence of contact (Kotovsky & Baillargeon, 2000; S. Wang, Kaufman, & Baillargeon, 2003). Based on looking time, infants behave as if they understand that objects are solid and move only when contacted by some outside force.

Another interesting expectation of infants is that objects require support—that an object cannot remain suspended in midair or it will
fall—and this, too, develops gradually over infancy. Baillargeon and her colleagues (1995) showed infants possible and impossible events reflecting the idea of support (see Figure 4.14). A gloved hand would push a box that sat atop a platform from left to right. In the possible event, the box stopped while firmly situated on the platform. In the impossible event, the box was pushed until only 15% of it rested on the platform. How did babies react to the impossible event? If they understand that objects need to be supported lest they fall, they should show surprise and increase looking time when observing the impossible event. The youngest infants (3-month-olds) weren’t surprised. As long as the box maintained some contact with the platform, they acted as if they expected it to remain on the platform and not fall. Beginning about 4.5 months of age, the amount of contact between the box and the platform became important, and by 6.5 months, infants expected that the box would fall unless a significant portion of it is in contact with the platform.

Other studies indicate that infants’ understanding of object cohesion and continuity continues to develop over the first year. For example, Figure 4.15 presents three ways in which Baillargeon and her colleagues have tested infants’ understanding of the role of height in object continuity. The first is in an occlusion experiment. A tall object is placed behind and, thus, is occluded by a shorter object, as shown in the top row of Figure 4.15. This is impossible, of course, and 4.5-month-old infants act surprised when this happens (Baillargeon & DeVos, 1991). Now consider nearly the same situation, but instead of the taller object being placed behind the shorter object, it is placed within it, a containment event, as shown in the second row of Figure 4.15. Now infants do not show surprise until about 7.5 months (Hespos & Baillargeon, 2001), and it is not until 12 months that they show surprise when a shorter object covers a taller object (S. Wang, Baillargeon, & Paterson, 2005), as seen in the bottom row of Figure 4.15. This pattern reflects what Piaget referred to as horizontal décalage (see Chapter 5), in which an ability—in this case understanding the physical relationship between short and tall objects—develops at different rates in different contexts.

As we have seen, infants’ knowledge of objects seems to be dominated by an expectation that inanimate objects behave in continuous (in the sense of being permanent and solid entities) and cohesive (as a bounded whole) ways, that contact is necessary for an inanimate object to move, and that objects must be supported or they will fall. Some of these expectations seem to develop

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**FIGURE 4.14** Example of possible and impossible events for object support. Although 3-month-old infants were not surprised by the impossible event, by 4.5 months of age infants begin to understand that the amount of contact between the box and the platform is important.

**Possible Event**

![Possible Event Diagram]

**Impossible Event**

![Impossible Event Diagram]

CHAPTER 4  INFANT PERCEPTION AND COGNITION

FIGURE 4.15 Three ways of assessing infants’ understanding of the role of height in object continuity. Depending on how infants are tested (that is, by an occlusion event, a containment event, or a covering event), they display an understanding of the role of height in object continuity at different ages.

Occlusion Event

Containment Event

Covering Event


early than others, and the range of contexts in which infants will show this knowledge increases with age and experience. Baillargeon (2008) proposed that infants possess an innate idea she called the principle of persistence, defined as “objects not only exist continuously and remain cohesive, they also retain their individual properties. According to this principle, no object can undergo a spontaneous or uncaused change in the course of an event” (p. 3). The principles of continuity and cohesion would be derivations of this more general principle. This does not mean that experience is unnecessary, however. For Baillargeon and her colleagues, when infants watch a physical event for the first time, their representation of it is initially impoverished, so that they may be attentive to only some violations of persistence. For example, they attend to the fact that an object cannot disappear at one location and appear at another without traversing the area in between but do not yet demonstrate expectations about the height or color of the objects. With increasing experience, their representations become enriched, and infants will demonstrate sensitivity to a broader range of violations of persistence (for example, they will
notice when the color or height of an object has unexpectedly changed). However, infants can develop a sensitivity to these secondary characteristics of objects—their color, height, shape—earlier under certain task conditions, such as when their attention is deliberately drawn to these features (T. Wilcox & Chapa, 2004).

There is an interesting aside to the work demonstrating infants’ often-substantial knowledge of support and solidity. Recall our comments about the discrepancy between infants’ (even newborns’) appreciation of object constancy and that of the preschooler (“How does the plane get so small?”). This discrepancy is also found for an understanding of support and solidity. For example, in search tasks, in which children must find an object hidden in one of several locations, 2-year-olds generally fail to display knowledge of these concepts, unlike their younger 6-month-old counterparts (Berthier et al., 2000; Hood, Carey, & Prasada, 2000). For example, Bruce Hood and his colleagues (2000) showed groups of 2- and 2.5-year-old children a ball being dropped onto a stage behind a screen. The screen was removed to reveal the ball resting on the floor of the stage (Experiment 1). After the children witnessed this event three times, the experimenter placed a cup on the floor of the stage, a shelf over the cup, and then a second cup on that shelf. This is illustrated in Figure 4.16. The screen was then replaced, and the ball was dropped behind the screen again. The children then saw the two cups, one on the shelf and one on the stage floor, and were asked to retrieve the ball. If they possessed a sense of solidity, as 6-month-old infants presumably do on the basis of looking-time procedures, they should search in the upper cup. However, if their sense of solidity is not fully developed, they should be just as likely to search in the cup on the floor of the stage, particularly because that is where they had successfully retrieved the ball three times before. Hood and his colleagues (2000) reported that only 40% of the 2-year-olds searched in the upper cup, whereas this percentage rose to 93% for the 2.5-year-olds.

This perplexing result, suggestive that infants have a more sophisticated understanding of spatial relations than 2-year-olds, likely is caused by the very different nature of the tasks (Keen, 2003). Older children must demonstrate an explicit (that is, conscious) understanding of solidity and support in the search tasks, whereas

**FIGURE 4.16** The apparatus used in a study by Hood et al. with 2- and 2.5-year-old children. Children watched as a ball was dropped behind the screen and saw that it rested on the floor. A shelf and two cups were then added to the stage, and the ball was dropped again behind the screen. Children were then asked to retrieve the ball.

Familiarize x 3  
Introduce Shelf + Cups, Then Search

the looking-time tasks used with infants require only implicit (that is, out-of-conscious awareness) knowledge. As such, postulating that infants who look longer at an impossible than at a possible event have the same type of knowledge as older children have for the phenomenon under question (here, support) is likely unwarranted. What young infants appear to possess, or to develop early, is implicit knowledge, which likely cannot be used as flexibly as explicit knowledge can.

Object Permanence

If a tree falls in the middle of the forest and no one is there to hear it, is there any noise? Young infants (presuming, of course, that they could communicate their response to us) would answer this perennial philosophical question very easily. Their answer would be no, for there can be no noise unless someone is there to perceive it. But the young infant would go on to say that there is also no tree and no forest. Nothing exists unless it is directly perceived or, more precisely, unless it is personally perceived by them.

This hypothetical philosophical discussion illustrates infants’ concept of object permanence or, more appropriately, the lack of object permanence. For infants who lack object permanence, out of sight is literally out of mind. Object permanence is obviously a cognitive skill necessary for normal intellectual functioning in all human cultures. The concept of object permanence was introduced by Jean Piaget (1954), and in this section we first describe Piaget’s account of object permanence. We then examine newer research, some of which challenges the interpretation, if not the findings, of Piaget.

Piaget’s account of object permanence. Piaget believed that between birth and 4 months, infants understand objects only as extensions of their own actions. Objects have no reality for babies independent of their perceptions or actions upon them. For example, a 2- or 3-month-old follows his mother with his eyes, but when she leaves his visual field, he continues to gaze at the point where he lost sight of her, not anticipating her reappearance at another location. Piaget saw the first semblance of object permanence at about 4 months. At this age, infants now attempt to retrieve an object that “disappears,” but only if the object is still partially visible. For example, babies at this stage fetch a toy that has been partially covered by a cloth, apparently realizing that the entire toy exists under the cloth even though they can see only a portion of it. They do not search, however, for a toy that is completely hidden, even if the hiding occurred right before their eyes. An exception to this behavior seems to be that late in this substage, infants search for a completely hidden object if they are moving in that direction when the object is hidden. So, for example, a 6-month-old infant playing with a favorite toy does not attempt to retrieve that toy when her father places it under a blanket while she is watching. She does retrieve it, however, if she is reaching for the toy in front of her as Dad places the blanket over it. Beginning at about 8 months, infants can retrieve a completely hidden object. However, object permanence is not yet complete, for if an object is hidden in one location and then later moved to a second, all while the child is watching, the infant searches at the first location and often acts quite surprised not to find the desired object. This is the A-not-B object permanence task, which we discussed briefly in Chapter 2.

Let us provide a real-life example of the A-not-B object permanence task. At approximately 10 months, my (DB) daughter Heidi was seated in her high chair, having just completed
Children’s Thinking

She was banging her spoon on the tray of the chair when it fell to the floor to her right. She leaned to the right, saw the spoon on the floor, and vocalized to me; I retrieved it for her. She began playing with the spoon again, and it fell to the right a second time. She again leaned to the right, saw the spoon on the floor, and vocalized until I returned it to her. Again, she played with the spoon, and again, it fell to the floor, but this time to her left. After hearing the clang of the spoon hitting the floor, Heidi leaned to the right to search for the spoon, and she continued her search for several seconds before looking at me with a puzzled expression. Heidi had been watching the spoon at the time it fell. Thus, when it fell the third time, she had both visual and auditory cues to tell her where it must be. But she searched where she had found the vanished object before. She trusted her past experience with the fallen spoon more than her perceptions. You see, up until this last event, Heidi’s behavior of searching to the right was always reinforced by the retrieval of her spoon. This pattern of reinforcement seemed to override her perceptual reasoning, leading her to persist in the reinforced behavior of searching to the right.

Beginning around 12 months, infants can solve problems like the one just described. What they cannot yet do, however, is solve what Piaget called invisible displacements. In invisible displacements, an object is hidden in one container and then hidden under another container out of the vision of the observer. An example from Piaget (1954) will help clarify this task:

Jacqueline is sitting on a green rug playing with a potato which interests her very much (it is a new object for her). She says “po-terre” [pomme de terre] and amuses herself by putting it into an empty box and taking it out again. . . . I then take the potato and put it in the box while Jacqueline watches. Then I place the box under the rug and turn it upside down, thus leaving the object hidden by the rug without letting the child see my maneuver, and I bring out the empty box. I say to Jacqueline, who has not stopped looking at the rug and who has realized that I was doing something under it: “Give papa the potato.” She searches for the object in the box, looks at me, again looks at the box minutely, looks at the rug, etc., but it does not occur to her to raise the rug in order to find the potato underneath. During the five subsequent attempts the reaction is uniformly negative. . . . Each time Jacqueline looks in the box, then looks at everything around her including the rug, but does not search under it. (p. 68)

According to Piaget, to solve invisible displacement problems, that is, to track their “chain of custody,” children must be able to mentally represent objects, something that is not found, according to Piaget, until about 18 months.

Piaget’s basic observations of the development of object permanence have been replicated in both large- and small-scales studies, using variants of the procedures he described (Kopp, Sigman, & Parmelee, 1974; Uzgiris & Hunt, 1975). However, researchers using some of the new techniques developed to study infant cognition believe that babies possess knowledge of the permanency of objects at earlier ages than Piaget proposed.

A new look at object permanence. Evidence of object permanence in young infants is probably best exemplified by Baillargeon’s work (Baillargeon, 1987; Baillargeon & DeVos, 1991) using the violation-of-expectation method, much as was done in her work on understanding support. In Baillargeon’s (1987) initial experiment, infants 3.5 and 4.5 months of age were habituated to a moving screen (see Figure 4.17). The screen was rotated 180 degrees, starting from being flat in a box with its leading edge facing...
FIGURE 4.17  The habituation and test (dishabituation) events shown to infants in the experimental and control conditions in the object permanence experiment by Baillargeon.

![Diagram showing habituation and test events](source)

**Experimental Condition**  (with box)

**Control Condition**  (without box)

- **Habituation Event**
  - [Diagram showing habituation process]

- **Test Events**
  - **Impossible Event**
  - **Possible Event**
  - **112° Event**
  - **180° Event**


the infant and rising continuously through an arc until it rested in the box with its leading edge farthest away from the infant. Once habituated to this event, infants in the experimental group were shown a colorful wooden block with a clown face painted on it, placed to the rear of the flat screen. In the impossible-event condition, the screen was rotated upward (exactly as in the habituation trials), which in the process obscured the wooden block from the infant’s sight. When the screen reached 90 degrees, the wooden block was removed, out of the view of the infant. The screen then continued its downward rotation until it lay flat. After this, the screen was rotated upward again, and the wooden block was replaced, again unbeknownst to the infant, so that it reappeared once more when the screen was being rotated toward the infant. From the
infant’s perspective, such a series of events (the continuous movement of the screen, despite the presence of an obstacle) should be impossible and violate the infant’s expectation of what should happen. If the wooden object were real in space and time, the screen should have stopped when it reached it. This, in fact, is what infants did see on some trials (the possible event), with the screen stopping at the point where it should have, given that there was an object on the other side. If the infants believed that the wooden block continued to exist, they should have shown surprise or increased looking time at the impossible event relative to the possible event. Infants in the control condition saw the same sequence of screen movements but were never shown the wooden block. Thus, these infants had no reason to express surprise. Infants in all conditions received four test trials.

The results of this experiment for the 4.5-month-old infants are graphed in Figure 4.18. As you can see, the infants in the experimental condition looked significantly longer at the impossible event than at the possible event. For the experimental infants, there was apparently nothing surprising about the possible event, but they knew that something was amiss when the screen failed to stop. No differences in looking time were found for the infants in the control condition. Similar findings were reported for 3.5-month-old infants (see Experiments 2 and 3 in Baillargeon, 1987; Baillargeon & DeVos, 1991). Other studies using this (Baillargeon & DeVos, 1991) and similar (Baillargeon, 2004) methods have produced similar results.

The most straightforward interpretation of these results is that the infants believed the block continued to exist even though it was out of their sight and were surprised when the screen failed to stop. Their performance in the impossible-event condition reflects not only a knowledge of the permanence of objects but also a knowledge that one solid object cannot pass through another (see the earlier discussion of solidity). This does not necessarily mean that Piaget was wrong but that infants’ understanding of the permanence of objects varies with the type of task used to assess it.

Other research using looking-time measures has shown that 5-month-olds code the spatial location of hidden objects. In a study by Nora Newcombe and her colleagues (1999), for instance, babies watched as an object was buried in a sandbox. After a 10-second delay,
the object was dug out. This was repeated four
times. On the fifth occasion, instead of digging up the object at the location where it had been hidden, the experimenter dug out the object from a different location (as near as 6 inches from where the first had been hidden). Babies looked significantly longer at these “trick” trials than at the previous trials, suggesting that they had coded the specific location of the objects. During a final experiment in this same study, infants were not surprised (that is, did not look longer) when a different object was retrieved from the sand. This finding suggests that spatiotemporal characteristics may play a central role in defining objects to young infants, with shape and color being unimportant.

One very interesting aspect of the findings of this study by Newcombe and her colleagues is that toddlers usually fail an analogous hiding task. In this task, toddlers watch as an object is hidden in a sandbox, then move to the opposite end of the box and are asked to retrieve the object. Not until 21 months of age can children solve this problem reliably (Newcombe et al., 1998), calling into question what, exactly, are the skills involved in solving these simple spatial tasks (Newcombe, 2002). Maybe the act of moving around the sandbox makes the task too demanding of children’s limited mental resources or disrupts their memory, accounting for the discrepancy. It is also possible that the difference between the implicit and explicit natures of the two tasks is responsible for the different findings. Children may possess an understanding of spatial relations at first only implicitly (Bremner & Mareschal, 2004; Newcombe, 2002), with explicit understanding, as reflected by an overt search task, being displayed only later in development. Recall that a similar interpretation was made for differences between infants’ and 2-year-olds’ understanding of support (Hood et al., 2000).

Richard Aslin might agree, stating that infants’ performance in the habituation/dishabituation task is further evidence of the Goldilocks effect, as we described earlier. When the same object appears in an unexpected spot, this amount of complexity is “just right,” leading infants to look longer at this type of event. In other words, it appears to infants there may be something to learn about the pattern of this particular object’s disappearance and reappearance in this instance. However, when a completely different object appears in a completely different location, infants may disengage because this is now too complex. That is, now two dimensions have changed—the object and the location. It’s likely that the violation-of-expectation method assesses perceptual knowledge, whereas the reaching task assesses self-aware thought, the ability to combine an old habit (finding the object) with a new cognitive update (looking under something). This is not to say that one method is better than the other but that the meaning of “infants possess object permanence” may differ depending on how object permanence is measured.

Other research has questioned Piaget’s results for the A-not-B task. As you may recall from Chapter 2, infants as young as 7.5 months of age will sometimes reach correctly on the B trials if the delay between hiding the object and searching for it is very brief (Diamond, 1985). As the delay increases, infants are more likely to look where the toy was previously hidden (that is, at the A location). This has caused some people to propose that memory or inhibition is involved in solving this task. It is not so much that infants fail to understand that objects have permanence in time and space but that they forget the object’s location or do not have the neurological maturation to inhibit a previously reinforced behavior (reaching to the correct A location) (Diamond, 1991).
Even when using Piaget’s reaching paradigm, differences in infants’ tendencies to successfully retrieve a hidden object are affected by some simple task variables, such as the number of times infants retrieve the object at the A location before it is switched to the B location in the A-not-B task (Marcovitch, Zelazo, & Schmuckler, 2002) or the familiarity of the objects being hidden. For example, in one study, 7.5-month-old infants were tested in the classic Piagetian object permanence tasks (retrieve an object hidden under a cloth) for either familiarized clay objects they had seen and reached for many times or novel objects (Shinskey & Munakata, 2005). Infants were tested for their preference when the items were uncovered and their understanding of object permanence when the items were covered. The results are shown in Figure 4.19. When the familiar and novel objects were visible, the infants almost always reached for the novel items, showing a classic novelty bias. However, when the objects were hidden, they were more likely to reach for the familiar item. Infants had a stronger mental representation for the familiar objects and, as a result, showed greater sensitivity for the continued existence of the familiar objects when hidden. In other words, they displayed evidence of object permanence for the familiar objects but not for the novel objects, suggesting that infants’ understanding of the permanence of objects, counter to Piaget, gradually develops as infants acquire stronger mental representations of objects through experience.

Early Number Concepts

A second proposed core-knowledge system is an understanding of quantities and numbers. Researchers have proposed that human infants share with other animals a nonsymbolic system for thinking about quantities in an imprecise and intuitive way, referred to as the approximate number system (ANS) (Feigenson, Libertus, & Halberda, 2013). This system is universal and continues to operate throughout the life span, but it is supplemented by explicit culturally invented systems for dealing with exact numbers (biologically secondary abilities), to which it is linked. We discuss the development of ANS in children and its connection with more advanced forms of mathematical cognition in Chapter 11. Here, we discuss two aspects of ANS in infancy: (1) numerosity and (2) ordinality (and see Geary, 1995, 2005). Numerosity refers to the ability to determine quickly the number of items...
in a set without counting, whereas *ordinality* refers to a basic understanding of *more than* and *less than*—for instance, that the number of items in one array is more (or less) than the number of items in another array. To do this, one does not necessarily have to understand the concept of *two or three*. Rather, infants display numerosity and ordinality by consistently being able to differentiate between two arrays with different numbers of items in them.

**Numerosity**

Very young infants can detect differences in numerosity—that is, they can tell the difference between two arrays that differ in the number of objects they contain (van Loosbroek & Smitsman, 1990). In research with slightly older infants, 10- and 12-month-olds watched as different numbers of graham crackers were placed inside two boxes (Feigenson, Carey, & Hauser, 2002). The boxes were then separated, and infants could crawl to retrieve the crackers from whichever box they pleased. Infants consistently crawled to the box that contained the larger number of crackers when the boxes contained one versus two and two versus three crackers, but they responded indiscriminately when the larger quantity was four or greater (for example, three versus four, two versus four, and three versus six).

This pattern of results with 10- to 12-month-old infants is similar to one reported for a group of rhesus monkeys (Hauser, Carey, & Hauser, 2000). In that study, researchers placed pieces of apples, one at a time, into one of two containers as the monkeys watched. The researchers then stepped back and watched to see which container the monkeys, living wild on an uninhabited island but accustomed to the human researchers, would approach first. Much like the human babies, the monkeys approached the box with the larger number of apple pieces in it for contrasts of zero versus one, one versus two, two versus three, and three versus four (the latter contrast being one the babies failed). When the number of apple pieces in a box exceeded four, the animals responded randomly. These findings suggest that both human infants within their first year of life and adult rhesus monkeys develop a natural understanding of *more than* and *less than*, at least for small quantities, making this ability evolutionarily old and not unique to humans.

No one claims that infants really “know” arithmetic the way that a first-grade child knows how to add and subtract small quantities. But some provocative evidence indicates that even 5-month-old babies’ concept of numerosity allows them to keep track of small changes in quantities, a behavior that looks like an understanding of how to add and subtract.

This is best illustrated in the study by Karen Wynn (1992). Wynn used the violation-of-expectation method to determine if 5-month-old infants could “add” and “subtract” small quantities. Wynn (1992) sat 5-month-old infants in front of a display. Infants were then shown a sequence of events that involved the addition or subtraction of elements. Two of these sequences are shown in Figure 4.20. One sequence (the possible outcome) led to the conclusion that $1 + 1 = 2$; the other sequence (the impossible outcome) led to the conclusion that $1 + 1 = 1$. Infants sat in front of a stage and watched as one object was placed on it (Step 1 in Figure 4.20). A screen was then raised, hiding the object (Step 2 in Figure 4.20). The infant then watched as a second object was placed behind the screen (Steps 3 and 4 in Figure 4.20). The screen was then lowered, revealing either two
objects (the possible outcome) or one object (the impossible outcome). If infants have some primitive concept of addition, they should be surprised and, thus, spend more time looking at the impossible outcome. This was exactly what occurred, both for the addition problem shown in Figure 4.20 and for a simple subtraction problem ($2 - 1 = 1$).

How can these results best be interpreted? On the surface, at least, infants seem not to be making only a perceptual discrimination between two arrays (that is, telling the difference between an array with one item in it and another with two). Rather, when they watch as one item is added to another behind a screen, they expect to see two items when the screen is dropped. This seems to require some rudimentary ideas about addition. They must infer that the second object was added to the first, without actually seeing that this was done (recall that the screen occluded their vision).

Others have replicated these results (Simon, Hespos, & Rochat, 1995), and research using methods much like those used with human babies has shown that 3- and 4-day-old chickens show similar quantitative abilities (Rugani et al., 2009), suggesting that such basic computation is not unique to humans. However, the interpretation of these findings is not without debate (Clearfield & Westfahl, 2006; D. S. Moore & Cocas, 2006). For example, some researchers suggest that babies are not responding to number but to the total amount of substance present (Mix, Huttenlocher, & Levine, 2002). In other words, infants are not doing primitive (and unconscious) addition and subtraction. They are responding to changes in the amount of “stuff” that is present in the various arrays. For example, rather than reflecting infants’ abstract understanding of integers (that is, there should be “1” or “2” objects behind the screen), performance on such tasks may be based on

**FIGURE 4.20** Sequence of events for the $1 + 1 = 2$ (possible) outcome and the $1 + 1 = 1$ (impossible) outcome from the experiment by Wynn (1992).

1. Object placed in case
2. Screen comes up
3. Second object added
4. Hand leaves empty

Then either: **possible outcome**
5. Screen drops ...
   ...revealing 2 objects

or: **impossible outcome**
5. Screen drops ...
   ...revealing 1 object

representations of the actual objects (for example, ♥ versus ♥ ♥), suggesting that decisions are based more on perceptual than on conceptual relations). Susan Carey (2009; see also Mandler, 2000; Mou & vanMarle, 2014) refers to this system of representation as parallel individuation and the explicit symbols as individual files. She points out that infants’ performance on this task and others that seem to tap into an infant’s knowledge of number is not affected by the ratio of the comparisons in the way that ordinality tasks are, as we describe shortly. Instead, performance on the task seems constrained by how many individual files an infant can represent in working memory. Much like the graham cracker study described earlier, infants seem limited to represent only three, maybe four, individual items in a set at a time.

**Ordinality**

Other research indicates that 6-month-old infants can tell the difference between quantities larger than four but that the ratio of the larger and smaller quantities must be large, indicating that reasoning about ordinality conforms to Weber’s law, used to describe the perceptual discriminability of many sensory stimuli. For example, using preferential-looking methods, 6-month-olds can tell the differences between large arrays of dots on a computer screen when the larger quantity is twice as numerous as the smaller quantity, such as 8 versus 16 or 16 versus 32. However, 6-month-olds fail to discriminate between arrays with smaller ratios, such as 8 versus 12 or 16 versus 24 (Cordes & Brannon, 2009; Xu, Spelke, & Goddard, 2005). The critical ratio (often referred to as the Weber ratio) for discrimination gets progressively finer with age, most drastically during the first year. A variety of factors influence infants’ abilities to discriminate different quantities of objects in arrays, including the density of the items in arrays (spaced out or packed together) and the size of the items (large items versus small items), making any definitive statements about what underlies these early abilities difficult. Many of these variables are controlled for in the studies referenced earlier by equating for these factors across habituation and test stimuli. As such, these results seem to represent more than infants’ simple differences in visual perception. In addition, infants’ quantity judgments are not limited to visual arrays. For example, 6-month-old infants can also distinguish between two sequences of 8 and 16 sounds (Lipton & Spelke, 2000) as well as between sequences of events (for example, a puppet jumping up and down four versus eight times) (J. N. Wood & Spelke, 2005).

This line of work is provocative and, regardless of interpretation, suggests substantially greater quantitative knowledge in young infants than was previously believed. However, it does not mean that infants and toddlers should be able to learn complicated mathematics given the proper instructions. The nature of their numerical competencies might not be fully known, but it seems relatively certain that it is not equivalent to the abilities found in children only a few years older.

**Newborn Statisticians?**

More recently, researchers have begun to ask to what extent infants can make inferences about the environment based on very limited experience. Six- to 12-month-old infants are sensitive to probabilistic relations when making inferences from samples to populations, and vice versa (Denison, Reed, & Xu, 2013). When 6- and 8-month-old infants were shown a box of ping-pong balls—four of which were red and one of which was
white—and an experimenter closed her eyes and randomly drew out a handful of balls, infants’ looking times suggested they found a sample of four red balls and one white ball more probable than a sample of one red ball and four white balls. That is, they looked longer at the improbable, or unexpected, event (one red ball and four white balls). Six-month-olds, but not 4.5-month-olds, extrapolated these probabilities from a larger population of ping-pong balls as well, expecting only one white ball and four red balls to be drawn from a population of, say, 100 balls in which 80 were red and 20 were white.

**Arguments Against Core Knowledge**

We think it’s fair to say that research over the past 30 years or so using the “new” infant technologies has demonstrated that babies have far more cognitive abilities than we once thought. However, not everyone believes that systematic changes in looking time reflect complex underlying cognitive abilities. These arguments are based on insights from computer modeling, dynamic systems theory, and Bayesian networks. For example, Richard Bogartz and his colleagues (Bogartz & Shinskey, 1998; Bogartz et al., 1997; see also Spencer et al., 2009) have argued that it is not necessary to attribute innate knowledge of physical objects to account for the findings of studies that use infants’ looking behavior as an indication of what they know. Bogartz and his colleagues (1997) “assume that young infants cannot reason, draw inferences, or have beliefs” (p. 411) and “that the infant does not enter the world with [knowledge of objects] nor does it acquire such knowledge of physical laws in the first 6 months of life” (p. 412).

How, then, can one explain the data if there are no innate conceptual constraints? Bogartz and his colleagues suggest that infants come into the world with a set of mechanisms for processing perceptual information and that infants acquire knowledge of objects through perceptual experience. The nature of perceptual processing produces looking patterns that Baillargeon, Spelke, and others interpret as innate knowledge. According to Bogartz and his colleagues (1997), however, infants’ perceptual processing “consists of analysis of the immediate representations of events, the construction in associative memory of the transformations of these immediate representations, abstraction of their forms, and the comparison of immediate perceptual representations to the representations stored in memory” (p. 411). All this processing takes time. In habituation/dishabituation tasks, infants look at familiar stimuli because it takes time to store memory representations. Novel events (that is, impossible events in the studies described earlier) take even more time because initial encoding of the stimuli needs to be done. Infants show a preference for looking at the novel (impossible) event over the familiar (habituated and possible) event simply because more processing is required to make sense of the former than the latter. There is no need to postulate innate knowledge of physical laws, only laws about how infant perception and memory work.

Another currently popular approach is **Bayesian statistical inference**, a mathematical probability theory that accounts for learning as a process by which prior knowledge is compared to currently observed evidence. For example, recall the work of Richard Aslin and colleagues that we described earlier in this chapter on the Goldilocks effect. This research demonstrated how infants develop expectations about the world based on the patterns that emerge in their environment. As they experience matches and mismatches between these expectations and what they perceive, they maintain or modify their expectations accordingly.
Specifically, when infants encounter mismatches, or unexpected information, looking longer at it provides them the opportunity to learn from the event and update their future expectations with this knowledge. There are several examples of infants seeming to compute probabilities, some of which we’ve already described, to reason about events in simple and complex patterns, tones, phonemes, words, colored shapes, and human actions (for a review, see S. P. Johnson & Hannon, 2015). The critical point about Bayesian inference models, then, is that they provide a principled explanation for how new evidence is combined with prior beliefs during the learning process.

To make the concept more concrete, we elaborate on just one example of 12-month-olds’ reasoning about objects moving out of a container with an occluded opening (Téglás et al., 2011). In this study, infants viewed movies of four objects, blue or red circles or squares, bounced randomly inside a circular container with an opening on the bottom (see Figure 4.21). After several seconds, an occluder covered the container from view for a period of 0 to 2 seconds before one object visibly exited through the bottom opening while the occluder was still in place. At this point, the occluder faded out. Researchers monitored infants’ looking time to assess how surprised infants were to see the object exit. Across 12 kinds of movies, three factors were manipulated that could be used to predict which object should exit first: the number of each type of object (in a configuration of three blue circles and one red square, it is more probable that a blue circle will exit first); their physical arrangement (objects near the bottom should be more likely to exit first); and the duration of the occlusion (the objects’ locations before occlusion are most predictive of which object will exit first when the duration of occlusion is short). To form correct expectations, infants must be able to integrate these three factors as well as some abstract knowledge about how objects move. In other words, they must hold prior beliefs that objects are unlikely to pass through walls and tend to move only short distances over brief periods of time and longer distances over longer durations. The results confirmed just that; 12-month-olds were capable of combining prior knowledge with current information to develop appropriate expectations. After a short occlusion, infants’ looking times reflected that their expectations were based on only the physical distance of each object. However, when occlusion duration increased to 1 second, infants’ looking times reflected that they considered both the number of objects of each type and their last-seen distance to the exit. Finally, when the occlusion was longer than 2 seconds, infants appeared to disregard the preocclusion distance of objects from the exit and based their expectations on the number of each object type. These findings suggest that infants are capable of combining experience related to physical arrangement, duration of occlusion, and the number of objects with more abstract principles of object motion to make probabilistic inferences.

**Figure 4.21** An example of the stimuli used by Téglás et al. (2011) to demonstrate that 12-month-old infants are capable of combining experience related to physical arrangement, duration of occlusion, and the number of objects with more abstract principles of object motion to make probabilistic inferences.

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abstract principles of object motion to make probabilistic inferences (see also Denison & Xu, 2010).

There has been much debate about the nature of infant cognition. Some researchers propose that infants are born with “core knowledge” for important aspects of their world that develop rapidly with experience (for example, Spelke & Kinzler, 2007), and still others propose that infants’ and toddlers’ cognitive skills are constructed via more domain-general mechanisms (for example, Newcombe, 2010; Spencer et al., 2009). We concur that infants possess perceptual systems that are tuned to a richly structured and predictable world and interact with developing attention and learning mechanisms. Together, these systems aid infants in discovering and making computational inferences about their environment. As Nora Newcombe (2010) states, Piaget’s fundamental ideas seem “now to have been absolutely right: that a biologically prepared mind interacts in biologically evolved ways with an expectable environment that nevertheless includes significant variation” (p. vi).

Section Review

Core knowledge refers to the idea that infants possess a small set of domain-specific systems of knowledge that have been shaped by natural selection and upon which new and flexible skills are built. There are at least three core-knowledge systems in infancy: object representation, knowledge of people and their actions, and an ability to represent numbers, or quantities.

Early Object and Number Representation

- From birth, infants seem to have a rudimentary understanding of object constancy, the knowledge that an object remains the same despite changes in how it is viewed.
- Infants’ understanding of object cohesion and continuity (understanding that objects have boundaries) develops over the first year, as reflected by experiments using the violation-of-expectation method.
- Baillargeon proposed that infants possess at birth the principle of persistence (knowledge that objects remain cohesive and cannot undergo a spontaneous or uncaused change in the course of an event).
- Object permanence refers to the belief that objects exist independent of one’s perceptions or actions. Piaget was the first to describe the development of object permanence and proposed that infants cannot retrieve a hidden object until about 8 months, cannot solve the A-not-B task until about 12 months, and cannot understand invisible displacements until about 18 months.
- By using variations of the violation-of-expectation method, researchers have demonstrated evidence of object permanence earlier than Piaget had proposed.
- Using variations of the violation-of-expectation method, researchers have also demonstrated evidence for simple quantitative abilities in infants. Among these are numerosity (the ability to determine quickly the number of items in a set without counting) and ordinality (a basic understanding of more than and less than relationships).

Newborns as Statisticians

- Infants seem capable of developing expectations about the probability that an event will occur based on their experiences.

Arguments Against Core Knowledge

- Some researchers argue that it is not necessary to postulate core knowledge...
or innate conceptual constraints; rather, infants are born with a set of mechanisms for processing perceptual information and acquire knowledge of objects through perceptual experience.

**Ask Yourself . . .**

13. What is meant by the core-knowledge approach to infant cognition? What are the main findings regarding infants’ understanding of objects, people, and quantitative relations?

14. What is object permanence? Describe two ways in which it has been measured. How might our interpretation of infants’ understanding of object permanence differ based on the findings of Piaget’s task and Baillargeon’s task?

15. What kind of statistics do infants seem able to do?

16. Are infants born as “blank slates”? What does modern research in infant perception and cognition contribute to this issue?

**WHAT IS INFANT COGNITION MADE OF?**

There is little debate that cognition and behavior change drastically over infancy. Brain growth is more rapid during the first 2 years than at any other time in postnatal life. Cognitive differences between the 10-month-old and the 2-year-old are dramatic, obvious to anyone who takes the time to look. Yet increasing evidence indicates that the huge changes in overt behavior that are apparent to all might be masking much smaller changes in underlying competencies. Infants seem to know a lot about their physical world from birth or shortly thereafter, and they may even be able to do simple computations.

Not everyone believes that the new research findings truly reflect advanced symbolic functioning or innate knowledge, of any type. For example, Kurt Fischer and Thomas Bidell (1991) argued that any particular infant skill should not be viewed in isolation but in the context of overall development. Rather than asking, for instance, when infants “really” have object permanence, Fischer and Bidell (1991) suggest that developmental researchers ask more fruitful questions, including these: “What is the developmental sequence of object knowledge from earliest infancy through early childhood? How is the development of this sequence related to developments in other domains? How is it constrained by the nature of perceptual and sensorimotor processes, which are partly regulated by the genome, and by environmental inputs? How are such constraints evident at various points in developmental sequences?” (pp. 223–224). These are similar to the arguments Marshall Haith (1993) made regarding infant perceptual abilities.

There is much excitement in infant research these days. Regardless of which interpretation one prefers, we think most researchers would agree that infants have far greater conceptual abilities than was previously believed, and every year, we learn something else that infants know or can do. We should not lose sight, however, of what infants cannot do. There is no evidence, for example, that infants can be taught arithmetic, reading, or chemistry. Infancy is still a special time, and the infant mind remains far different from the mind that resides in the 3-year-old child. Remembering the limits of infant cognition is sometimes difficult when we look at all the things infants can do, but it is a thought we shouldn’t lose.
KEY TERMS AND CONCEPTS

accommodation (of the lens)  Goldilocks effect  ordinality
A-not-B object permanence task  habituation  other-race effect
Bayesian statistical inference  implicit measures  perceptual narrowing
convergence (of the eyes)  intersensory integration  phonemes
coordination (of the eyes)  intersensory matching  principle of persistence
core knowledge  numerosity  schema
differentiation theory  object cohesion and continuity
dishabituation  object constancy
explicit measures  object permanence
externality effect

SUGGESTED READINGS

Scholarly Works

Baillargeon, R. (2008). Innate ideas revisited: For a principle of persistence in infants’ physical reasoning. *Perspectives on Psychological Science, 3,* 2–13. This article reviews research by Renée Baillargeon and her colleagues on object representation in infants using the violation-of-expectation method. She proposes the principle of persistence, in which babies seem to know coming into the world something about the continuity of objects.

Kelly, D. J., et al. (2007). The other-race effect develops during infancy. *Psychological Science, 18,* 1084–1089. These leading researchers in the field of face processing in infants present findings demonstrating the other-race effect in infancy. The article also provides a good example of how researchers test hypotheses regarding how infants process complicated information.

Spelke, E. S., & Kinzler, K. D. (2007). Core knowledge. *Developmental Science, 10,* 89–96. Elizabeth Spelke and Katherine Kinzler present evidence for the core-knowledge perspective of infant cognition, listing five areas in which core knowledge is proposed to exist.

Xu, F., & Kushnir, T. (2013). Infants are rational constructivist learners. *Current Directions in Psychological Sciences, 22*(1), 28–32. This article describes empirical evidence that infants are best characterized as rational constructivist learners. The authors describe the new approach against the background of nativism and empiricism, arguing that the new rational constructivism perspective blends elements of both while adopting probabilistic models of cognition.

Reading for Personal Interest

Dobbs, D. (2005). Big answers from little people. *Scientific American Mind, 16*(3), 38–43. This article, written for the layperson, examines the latest research into infants’ cognitive abilities, focusing on the work of Elizabeth Spelke, Harvard developmental psychologist and advocate of the core-knowledge approach.

Rochat, P. (2004). *The infant’s world.* Cambridge, MA: Harvard University Press. Philippe Rochat examines the development of infant social cognition, taking an ecological perspective somewhat different from the core-knowledge perspective as advocated by Elizabeth Spelke and her colleagues.