Part I

Perception and Cognition

Introduction

This section provides detailed coverage of current research on infants' ability to perceive and remember information in their world, and to act on the basis of this information. Knowledge of infants' perceptual and memory capacities, and at a higher level, their knowledge and understanding of the physical and social world they inhabit, is vital in itself and also for what it may imply about their social behavior and emotional responses. For instance, an ability to perceive parents and to discriminate them from other adults is an important precondition for the formation of attachment relationships, and the ability to perceive and discriminate sounds is likewise a necessary condition for the receptive side of verbal communication.

As indicated in the general introduction, there has been a revolution in what we know about young infants' perceptual abilities. In general, the current view is that young infants and even newborns have well-established perceptual capacities. In chapter 1, Slater reviews evidence on visual perception, concluding that even newborns perceive an objective world. This might lead one to conclude that there is no perceptual development during infancy, but current evidence suggests that phenomena such as object unity, in which we as adults "fill in" occluded parts of objects, are not present at birth and develop during the first four months or so. Phenomena such as these provide an indication that it is no longer easy to provide a straightforward distinction between perception and cognition, because the ability to complete the hidden parts of an object can be considered as either a high-level perceptual capacity, based on Gestalt principles, or a cognitive ability akin to knowledge of the permanence of hidden objects. One of the challenges for future work is to establish which of these conceptualizations is most appropriate. Slater also reviews current evidence on a key aspect of social perception: face perception. Again there is evidence that newborns have at least basic processes in place for perception of and discrimination between faces, abilities that become more refined as the infant gets older.

There is a tendency to concentrate investigation on infant visual perception at the expense of the other senses. However, social stimuli in particular have important auditory properties; information about people is contained as much in the auditory as the visual modality. In chapter 2, Fernald explains the techniques for measuring infants' auditory abilities and reviews the resulting evidence. Like the case of visual perception, young infants have impressive auditory abilities that develop further with age. Additionally, there is evidence for auditory learning and discrimination even before birth. The later sections of the chapter focus on infants' ability to perceive speech. Young infants show impressive abilities to discriminate speech sounds and are particularly attentive to the particular intonation patterns that adults use in their infant-directed speech. Clearly, these abilities are critical for the later development of language comprehension and production (see chapter 15).

Any account would be incomplete without a treatment of the development of action. Until relatively recently, accounts of motor development were offered according to which cortical developments led to motor activities coming progressively under purposive control. In chapter 3, Smitsman dispels the notion that the development of action can be explained purely in terms of changes in the brain, pointing out that development occurs through a dynamic process of self-organization in which brain, biomechanics, and environment interact. Dynamical systems theory has successfully modeled some of the changes that take place, and one benefit of this approach is that it can incorporate links between perception and action. Using reaching and grasping as an example, Smitsman indicates the need for an approach that takes account of a wide range of bodily and environmental factors. Postural control is required to support successful reaching, and thus motor subsystems must interact to produce the action. Also, it is evident that infants take account of environmental structure with growing precision in action guidance. Thus, to present a full account of the development of action it is necessary not just to model the relationship between different motor components, but to include in the model the relationship between these organism properties and the structure of the environment.

Although young infants have quite advanced perceptual capacities, it appears they have to develop the ability to use perceptual information to guide action. In chapter 4, Bremner reviews evidence for advanced awareness of objects in early infancy, but contrasts this literature with the wealth of evidence showing that it may be many months before individuals are able to use this information to guide their actions. Late emergence of knowledge-guided action cannot be put down to motor immaturity, and Bremner suggests that an important aspect of infant development concerns the discovery and construction of relationships between perception and action. One of the controversies in this area concerns the nature of early competence. Some researchers claim innate knowledge and the ability to reason about events, others that competence is based on lower-level perceptual principles. Bremner suggests that although the latter interpretation may be more appropriate, the capacities revealed in early infancy are vital precursors of cognitive abilities that emerge later in infancy.

None of the above abilities is possible without at least some rudimentary form of memory. Not so long ago, it was suspected that memory was quite severely limited in early infancy. In chapter 5, Rovee-Collier and Barr provide a thorough review of the methods used to investigate infant memory and learning, methods that range from simple habituation as evidence for recognition memory, to deferred imitation as evidence for recall of an action sequence. The evidence indicates that even in early infancy, memory is a good deal more long-lived and specific than was once thought. Additionally, the duration of memory can be dramatically increased by the use of simple brief reminders of the task and setting. Rovee-Collier and Barr conclude that although memory is somewhat limited in terms of duration and speed of retrieval, infant memory systems show all the same properties as adult systems, permitting them to retain a great deal of detailed information about the world over long periods.

Although various authors touch on the relationship between brain development and the phenomena with which they are dealing, these relationships deserve a thorough treatment in themselves. In chapter 6, Johnson argues for the need to take a multidisciplinary approach to developmental questions that takes account of what we know of the brain's development as well as the development of behavior. Additionally, he argues against the older notions that psychological developments can be put down simply to brain maturation, indicating that complex two-way processes are involved through which the development of the brain actually results from exercise of the behaviors that it controls. The reader will find many of the topics treated in earlier chapters revisited within this framework. These include face recognition (chapter 1), visually guided action (chapter 2), object permanence (chapter 4), and memory (chapter 5). The primary emphasis in every case is what can be gained from an approach that interprets development in terms of the dynamic relationship between development of brain and behavior, and Johnson makes a convincing case for the merits of this approach.

With the exception of material on face and voice perception, the first six chapters in this section focus on literature concerning infants' perception and knowledge of the physical world. The final three chapters change the focus to perception and understanding of self and others – abilities that are necessary components of infants' functioning as social beings. In chapter 7, Rochat presents evidence of infants' ability to detect disparities between proprioceptive information about limb movements and asynchronous visual information about their limb movements fed back to them experimentally. The conclusion is that intermodal information about limb position and movement, along with "double touch" information that arises when the infant touches a part of self, provides early perceptual specification of self. This implicit perception arises from exploration and exists long before explicit self-recognition. Rochat also claims social origins of self-knowledge, arguing that in imitation and emotional matching, young infants match their actions and emotions to those of others, and so develop an implicit sense of interpersonal self.

The final two chapters relate closely, but take rather different perspectives. In chapter 8, Butterworth takes a comparative perspective on joint visual attention in human infants. Interpretation of the locus of another's gaze or point is a complex spatial skill, and Butterworth presents evidence that infants are initially capable of identifying locus of attention only within the range of space in which viewer and target are simultaneously visible, later extending this to wider space. Additionally, younger infants tend to use head orientation rather than eye orientation to infer locus of attention, and even adults do not apply a precise geometric vector solution. Interestingly, infant abilities in these tasks are matched or exceeded by adult chimpanzees. Pointing, in principle, is a simpler spatial skill, but important questions arise as to how human infants and apes use it. Although apes do point, they do not appear to use pointing as a declarative gesture. In contrast, infants' pointing appears to be declarative from its emergence, indicating clear differences between humans and apes.

In chapter 9, addressing some of the same topics, Reddy focuses on what infants' actions tell us about early knowledge of the mind. Specifically, she looks at infants' knowledge of attention and intention by others. Knowledge of attention is revealed both in infants' subtle responses to the attentional acts of others, and in their attempts to direct the attention of others. Less is known about understanding of intentionality but there is evidence for its roots in early infancy. For instance, 4-month-old infants respond appropriately to playful intentions of others. Later, 9-month-olds show the beginnings of ability to read the intentions of others in their acts. Around the same time, infants begin to respond to parental commands and occasionally to show playful noncompliance, cases of teasing that Reddy interprets as implying growing awareness of others' intentions and how these can be disrupted. Abilities of this sort are identified as evidence for an implicit theory of mind, a capacity that is essential for the development of later social competence.

Chapter One

Visual Perception

Alan Slater

Introduction

The major characteristic of perception, which applies to all the sensory modalities, is that it is organized. With respect to visual perception, the world that we experience is immensely complex, consisting of many entities whose surfaces are a potentially bewildering array of overlapping textures, colors, contrasts, and contours, undergoing constant change as their position relative to the observer changes. However, we do not perceive a world of fleeting, unconnected retinal images; rather, we perceive objects, events, and people that move and change in an organized and coherent manner.

For hundreds of years there has been speculation about the development of the visual system and of perception of an organized world; however, answers to the many questions awaited the development of procedures and methodologies to test infants' perceptual abilities. Many such procedures are now available and, since the 1960s, many relevant infant studies have been reported. The findings from many of these studies are described in this chapter. The chapter is in four main sections. In the first section, "Theoretical Overview," an account is given of the theories of visual development that have helped shape our understanding of the infant's perceived world. In order to begin the business of making sense of the visual world, it has to be seen, and considerable research has been carried out to describe the sensory capacities of the young infant. An account of some of this research is given in the section headed "Sensory and Perceptual Functioning." In the next section, "Visual Organization at and Near Birth," research is described that has investigated the intrinsic organization of the visual world. Several lines of evidence converge to suggest that infants

*The author's research described in this chapter has been supported by research grants RC00232466 and R000235288/237709 from the Economic and Social Research Council. Earlier versions of some of the material contained in this chapter have appeared in Bremner, Slater, and Butterworth (1997), Vital-Durand, Atkinson, and Braddick (1996), and Slater (1998).

are born with some representation of the human face, and it has become apparent that infants rapidly learn about their visually perceived world. These themes are discussed under the headings "Is there an Innate Representation of the Human Face?" and "Early Experience and Learning." In the final section, emerging questions, paradigms, and issues are discussed.

Theoretical Overview

Until recent times the majority of theories of visual perception emphasized the extreme perceptual limitations of the newborn and young infant. For example, the "father of modern psychology" William James claimed (1890, Vol. 1, p. 488), in one of the most memorable phrases in developmental psychology, that "the baby, assailed by eyes, ears, nose, skin and entrails at once, feels it all as one great blooming, buzzing confusion." Hebb (1949), and Piaget (1953, 1954) argued that visual perception is exceptionally impoverished at birth and suggested that its development is a consequence of intensive learning in the months and years from birth. Hebb (1949, pp. 32–33) concluded that "The course of perceptual learning in man is gradual, proceeding from a dominance of colour, through a period of separate attention to each part of a figure, to a gradually arrived at identification of the whole as a whole: an apparently simultaneous instead of a serial apprehension," and he suggested that, "it is possible then that the normal human infant goes through the same process, and that we are able to see a square as such in a single glance only as the result of complex learning." Piaget (1953, p. 62) said of the young infant's vision: "Perception of light exists from birth and consequently the reflexes which insure the adaptation of this perception (the pupillary and palpebral reflexes, both to light). All the rest (perception of forms, sizes, positions, distances, prominence, etc.) is acquired through the combination of reflex activity with higher activities." Piaget did not discuss visual development in any detail. However, his constructionist approach suggested that perception becomes structured, in a sequence of stages as infancy progresses, as the infant becomes able to coordinate more and more complex patterns of activity. Thus, many perceptual abilities, such as intersensory coordination, size and shape constancy, an understanding that hidden objects continue to exist, and understanding of space and objects, develop relatively late in infancy.

The obvious alternative to learning or constructionist accounts of visual development is to adopt a nativist view that the ability to perceive a stable, organized visual world is an innate or inherent property of the visual system. A coherent and influential Gestalt theory of perception was developed by three psychologists, Max Wertheimer (1890–1943), Kurt Koffka (1886–1941), and Wolfgang Kohler (1887–1967). The Gestalt psychologists listed rules of perceptual organization that describe how groups of stimuli spontaneously organize themselves into meaningful patterns (research by Quinn and his colleagues into the Gestalt organizational principles of similarity, good continuation, and closure is described later). The Gestalt psychologists believed that the organization of visual perception is the result of neural activity in the brain which, in turn, depends on electrochemical processes. These physical processes obey the laws of physics, and are a fundamental characteristic of the human brain. It therefore follows that visual organization is a natural characteristic of the human species and is therefore innately provided.

The distinguished American psychologist J. J. Gibson (1904–1979) was for many years a leading critic of the empiricist or constructivist position. Gibson (1950, 1966, 1979) argued that the senses, or "perceptual systems," have evolved over evolutionary time to detect perceptual invariants directly, and without the need for additional supplementation by experience. Invariants are higher-order variables of perception that enable observers to perceive the world effectively, without the need for additional, constructive processes. Such invariants specify constancy of shape and size of objects, the permanence and properties of objects, the three-dimensional world of space, and so on: "Perception is not a matter of constructing a three-dimensional reality from the retinal image, either in development or in the perceptual acts of adults. The structure of the environment is 'out there' to be picked up, and perception is a matter of picking up invariant properties of space and objects" (Bremner, 1994, p. 118). Gibson was not a nativist. The invariances that infants detect cannot be easily specified, and perceptual development depends on the distinctive features that are detected at different ages, an empirical matter that cannot be easily resolved theoretically. However, when researchers began to discover perceptual abilities in young infants that could not be explained by recourse to empiricist, learning, and constructivist views, it was appealing to interpret findings in terms of Gibson's views: since perception is direct and does not need to be enhanced by experience, then Gibson's theory was the only "grand theory" able to accommodate the findings.

In recent years it has become apparent that Piaget's and Gibson's views both have much to offer: Piaget because he emphasized the role of action in sensorimotor development, and Gibson because his theory allows for the possibility of innate perceptual organization. These points will be touched on later in the chapter. No one would doubt that considerable learning about the visual world has to take place. However, as soon as research into infant perceptual abilities began in earnest, from the early 1960s, it became apparent that extreme empiricist views were untenable. As early as 1966 Bower concluded that "infants can in fact register most of the information an adult can register but can handle less of the information than adults can register" (p. 92). Research over the last 40 years has given rise to conceptions of the "competent infant," who enters the world with an intrinsically organized visual world that is adapted to the need to impose structure and meaning on the people, objects, and events that are encountered. This research has given rise to a number of theoretical views, concerned with specific aspects of visual development. Some of these views are described in the chapter, and an overview of some recent approaches is given in the final section.

Sensory and Perceptual Functioning

Unlike the other senses, there is no opportunity for visual experience prior to birth. It is therefore not surprising to find that the visual world of the newborn infant is quite different from that of the adult. Figure 1.1 shows schematic horizontal sections through the (left) eyes of the adult and the neonate to illustrate differences in overall size, in the shape of the lens, and in the depth of the anterior chamber. At birth the eye, like the brain, is relatively well developed, and both increase in volume about three or four times compared with the rest of the body, which increases about 21 times to reach adult size. Clearly,

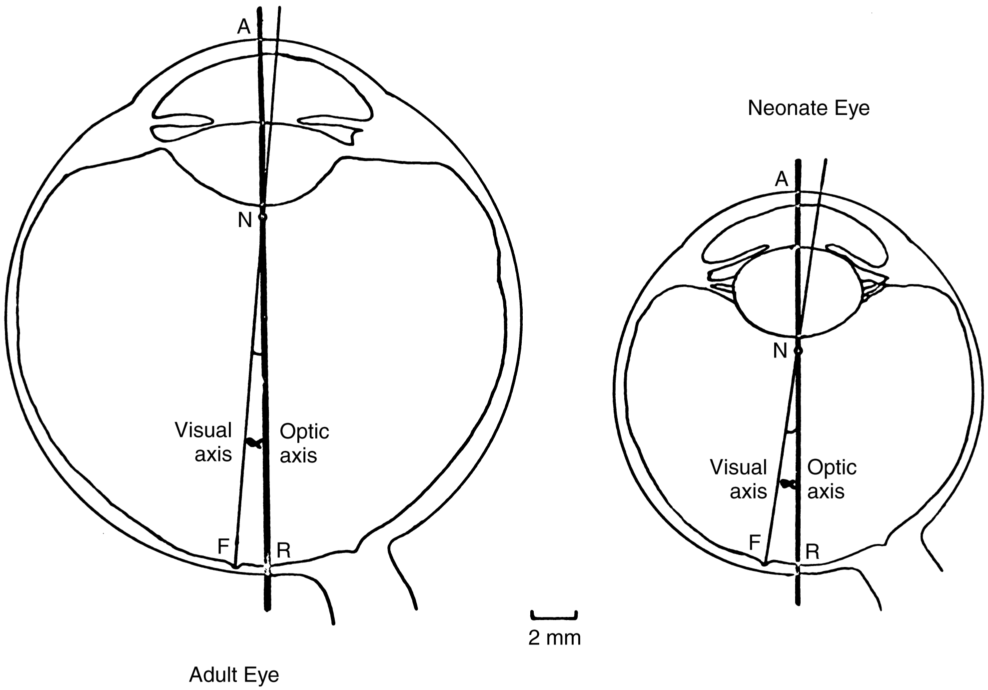

Figure 1.1 Schematic horizontal sections through the (left) eyes of the adult and neonate (to scale), to illustrate differences in gross size, in the shape of the lens, and in the depth of the anterior chamber. F, fovea; R, retina.

the eye and brain are relatively well developed at birth. At the time of normal birth (i.e., term) the peripheral retina of the eye is quite well developed, but the central retina (the macular region and the fovea) is poorly developed and undergoes considerable post-term changes (a detailed account of this development is given in Hainline, 1998). In order to perceive the visual world the perceiver needs a reasonable level of visual acuity (the ability to resolve detail), and the ability to distinguish the boundaries, colors, luminance levels, and textures of surrounding surfaces. The ability to track moving objects in the environment and to fixate (foveate) objects of interest is important, and depth perception is necessary to discriminate surfaces against the background. Excellent recent accounts of the development of infant vision are to be found in Atkinson (2000), Hainline (1998), and in various chapters in Vital-Durand, Atkinson, and Braddick (1996). A brief account of the development of visual functions is given here.

Contrast Sensitivity, Visual Acuity, Accommodation, and Color Vision

It is not surprising to find that the visual information detected by the newborn infant is impoverished when compared with that detected by the adult. Sensitivity to contrast differences is poor. A black and white pattern gives a contrast approaching 100 percent, and under good viewing conditions adults can discriminate between shades of gray giving contrast values of less than 1 percent; a contrast value of 30–40 percent is close to the newborn's threshold of detectability. Visual acuity is also poor. The most commonly used procedure to measure visual acuity is the visual preference method, often called preferential looking, or PL. In this procedure black and white stripes or gratings are shown to the infant at a distance of some 20 to 40 cm from the eyes, each stripe pattern paired with a gray patch of equal overall luminance. Infants tend preferentially to fixate the member of a stimulus pair they find more salient or interesting, and stripes are more interesting than a gray field, so if the stripes can be resolved, the infants more often look to that side than the other. If the stripe width is too small, however, the detail will not be visible, and no preference is observed. The infant's looking to each side is recorded by an observer, watching through a peephole or on a video monitor, and the smallest stripe width that is reliably preferred to the gray is taken as the estimate of acuity.

An alternative method for assessing visual acuity, and other visual functions, is measurement of visually evoked potentials (VEP). This consists of recording activity in the visual cortex (at the back of the skull) via electrodes placed on the scalp. When a stimulus such as a grating or checkerboard is presented, it is repeatedly phase-reversed (i.e., its dark elements switch to light as its light elements switch to dark). If the stimulus is registered by the visual system, the evoked potential signal should have a frequency component that matches the frequency of phase reversal.

Preferential looking studies suggest that neonate visual acuity is poor, about 1 to 2 cycles per degree, which is around 20/600 Snellen (Banks & Dannemiller, 1987; Brown, Dobson, & Maier, 1987; von Noorden, 1988; see also Hainline, 1998). (Adult visual acuity is typically around 30 cycles per degree, or 20/20 vision.) Thus, a neonate could resolve black and white stripes about one-eighth of an inch wide at a distance of 30 cm. Use of the visually evoked potential gives a more optimistic estimate (Hamer, Norcia, Tyler, & Hsu-Winges, 1989; Marg, Freeman, Peltzman, & Goldstein, 1976; Sokol, 1978). Acuity improves rapidly. The evoked potential technique suggests acuity is nearly adultlike by 6 months of age, but the preferential looking method indicates that more development in acuity occurs after this time (Banks & Dannemiller, 1987). The reasons for the discrepancy between the two procedures remain unclear (Banks & Dannemiller, 1987). As a rough guide, Figure 1.2 gives an indication of how the mother's face might look to a newborn infant, and how she might look to us: while the image is degraded and unfocused for the newborn, enough information is potentially available for the infant to learn to recognize the mother's face.

Accommodation refers to changes in the shape of the lens to focus on objects at different distances. Accommodation is initially poor, but since acuity is poor at birth it is likely that the "fine-tuning" afforded by accommodative changes makes little difference to the clarity of the perceived image. Accommodation responses improve along with changes in acuity, so that from 2 months, or earlier, all normal infants alter their accommodation in the appropriate direction as the distance of a visual target changes (Hainline, 1998; Howland, Dobson, & Sayles, 1987).

Figure 1.2 A face as it might appear to a newborn (left) and to us.

Newborn infants have been found to be limited in their abilities to detect color. A common misperception is that neonates are "color-blind," but this is not true. Hainline (1998, p. 27) summarizes research on infant color vision as follows: "It is difficult to know for certain, but it is probably safe to say that even young infants have a form of colour vision and it is probably like that of adults, (although) colours probably appear less intense than the same colours would to an older infant or adult."

Eye Movements, Scanning, and Fixations

Foveation consists of directing one's gaze to items of interest in the visual array. Foveation is most readily accomplished in humans via eye movements, although head and body movements also contribute. Even newborn infants foveate small objects, if they are motivated and the object is not too difficult to see (i.e., if it can be distinguished against the background and is close to the eyes). However, there are limitations in very young infants' abilities successfully to produce certain eye movements. For example, until 8 to 10 weeks of age, infants rarely engage in smooth pursuit, or the tracking of a slowly moving small target (Aslin, 1981). Saccadic eye movements are rapid movements which point the fovea at targets of interest: when reading a book such eye movements quickly direct the eye along the line of print. It has been observed that when one target disappears and another reappears young infants will often "approach" the new stimulus with a series of saccades rather than just one (Aslin & Salapatek, 1975). These are called "step-like" saccades. However, not all studies have found this apparent immaturity (Hainline & Abramov, 1985). Hainline (1998) points out that adults will occasionally produce step-like saccades when they are tired or inattentive, and suggests that perhaps the frequency of such saccades in infants might also be caused by lack of attention to the stimuli that are shown them in laboratory tests. She says that "We do not regularly observe step-saccades when infants look at natural scenes, so they may be an artifact of the laboratory," and concludes

"In general, the saccadic system seems quite mature and ready to function to reorient the fovea at high speeds, even early in life" (p. 36).

In summary, neonates seem to be limited in visual scanning skills, although attempts at foveation are readily observed. All types of eye movements are observed in young infants, and the eye movement and fixation system is mature by around 4 months (Hainline, 1998).

Depth Perception

> For those of a creationist bent, one could note that God must have loved depth cues, for He made so many of them. (Yonas & Granrud, 1985, p. 45)

By being physically separated in space the two eyes provide slightly different images of the perceived world. Detection of these small differences, or disparities, provides the basis for an important binocular cue to depth, stereopsis, in which the disparities are interpreted by the visual system as actual depth differences, and so gain three-dimensionality. The presence of stereopsis has been tested in infants by presenting them with two stimuli, one to each eye, the two images being slightly disparate: the infant wears goggles which allow the presentation of different images to the two eyes. If the infant has stereopsis, and fuses the images, a figure or shape is seen, and this is looked at in preference to a stimulus which does not produce a stereoscopic shape. Several researchers have reported that stereopsis appears around the end of the fourth month from birth (Braddick & Atkinson, 1983; Held, 1985; Teller, 1983). In adults very fine disparities can be detected and give rise to depth information. This fineness of stereopsis, called stereoacuity, improves rapidly from the onset of stereopsis and approaches adult levels within a few weeks (Held, 1985).

There are many other depth cues. Motion-carried, or kinetic depth cues are responded to at an early age. Newborn infants will selectively fixate a three-dimensional stimulus in preference to a photograph of the same stimulus, even when they are restricted to monocular viewing and the major depth cue is motion parallax (Slater, Rose, & Morison, 1984). Infants as young as 8 weeks perceive three-dimensional object shape when shown kinetic random-dot displays (Arterberry & Yonas, 2000). Appreciation of pictorial depth cues – those monocular cues to depth that are found in static scenes such as might be found in photographs – has been found from about 5 months. In an early experiment Yonas, Cleaves, and Pettersen (1978) used the "Ames window," a trapezoidal window rotated around its vertical axis. When adults view the two-dimensional Ames window monocularly a powerful illusion is perceived of a slanted window with one side (the larger) closer than the other. Yonas et al. reported that 6-month-olds are twice as likely to reach for the larger side of the distorted window than for the smaller side, suggesting that this depth cue is detected by this age. Sen, Yonas, and Knill (2001) have described a recently discovered static monocular cue to depth. This illusion is shown in Figure 1.3. In their experiment Sen et al. found that 7-month-olds, but not 5- or 5.5-month-olds, when tested monocularly, reached for the apparently closer end of the fronto-parallel cylinder. This finding gives further support to their suggestion that sensitivity to static monocular depth cues first appears around 6 months from birth.

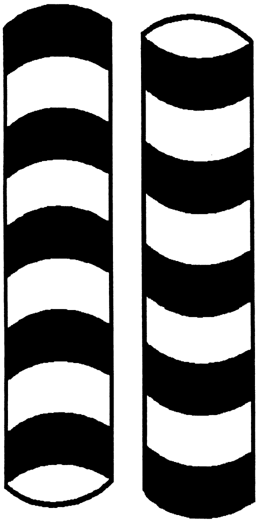

Figure 1.3 A 2D version of the 3D illusion used by Sen et al. (2001).

Overview

Some common myths about early vision can be dispelled. It is certainly not the case that babies are born blind, neither is it true that their vision is "locked on" at a particular distance from the eyes. The immediate input to the visual system is the image that falls on the two-dimensional retinae of the eyes. Although in no sense do we (or infants) ever "see" this retinal image, a commonly expressed view is that, since this image is upside down and reversed from right to left, at birth infants see the world similarly distorted. The simplest experiment convinces us that babies see the world the "right way round": if a light is shone to the left, or right (or up or down) of the baby's looking position the baby will turn its eyes in the correct direction. Of course, if the visual world were inverted or reversed the babies would look in the opposite direction, which they don't! Newborn infants also display some degree of color vision.

Clearly, the young infant's world is impoverished compared with that of the adult, but many visual functions approach adult standards three or four months from birth. Even the poor vision of very young infants does not hamper their development: there is "little indication that young infants are handicapped by their purported primitive visual abilities" (Hainline, 1998, p. 5). Young infants do not need to scrutinize the fine print in a contract, or to see things clearly at a distance. The most important visual stimuli are to be found in close proximity, and better acuity, which might allow infants to focus on distant objects that are of no relevance to their development, might well hinder, rather than promote, their development. Hainline (1998, p. 9) summarizes it rather nicely: "visually normal infants have the level of visual functioning that is required for the things that infants need to do."

Visual Organization at and Near Birth

We have seen that scanning abilities, acuity, contrast sensitivity, and color discrimination seem to be limited in neonates. However, despite these limitations the visual system is functioning at birth, and in this section several types of visual organization that are found in early infancy are discussed. Many parts of the brain, both subcortical and cortical, are involved in vision, but it is reasonable to claim that visual perception, in any meaningful sense, would not be possible without a functioning visual cortex, and this is discussed in the next section.

Cortical Functioning at Birth

The cortex is responsible for humans' memory, reasoning, planning, and many visual skills. The ability to foveate and to discriminate detail is also mediated by the visual cortex, and we presented evidence above which suggests that newborns can foveate stimuli. However, it has been proposed (Bronson, 1974) that the visual cortex is not functional at birth, and that the visual behaviors of infants for around the first two months from birth are mediated by subcortical structures such as the superior colliculus, which is particularly involved in the control of eye movements. Other researchers have also claimed that there is a shift from subcortical to cortical functioning around two months from birth (e.g., Atkinson, 1984; Johnson, 1990; Johnson & Morton, 1991; Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995).

A critical test of cortical functioning is discrimination of orientation. In primates, orientation discrimination is not found in subcortical neurons, but it is a common property of cortical cells, and orientation selectivity is therefore an indicator of cortical functioning. Two studies tested for orientation discrimination in newborns (Atkinson, Hood, Wattam-Bell, Anker, & Trickelbank, 1988; Slater, Morison, & Somers, 1988). In these, newborn infants were habituated to a black and white stripes pattern (grating), presented in an oblique orientation, and on subsequent test trials they clearly gave a preference for the same grating in a novel orientation (the mirror-image oblique of the familiarized stimulus).

This finding is an unambiguous demonstration that at least some parts of the visual cortex are functioning at birth. The presence of visually evoked potentials (referred to earlier in the section on visual acuity) also implies cortical functioning. Several accounts have attempted to describe which parts of the visual cortex may be more functional than others (e.g., Atkinson, 1984, 2000; Johnson, 1990). However, even if the visual cortex is immature, it is difficult to know in what ways this imposes limitations on visual perception. As Atkinson and Braddick (1989, p. 19) have put it, "we do not really have any idea how little or how much function we should expect from the structural immaturity of new-born visual cortex." Certainly, as will be described in the next sections, it has become clear that the newborn infant is possessed of many ways in which to begin to make sense of the visual world.

Figure 1.4 A newborn infant being tested in a size constancy experiment.

Shape and Size Constancy

As objects move, they change in orientation, or slant, and perhaps also their distance, relative to an observer, causing constant changes to the image of the objects on the retina. However, and as indicated in the Introduction, we do not experience a world of fleeting, unconnected retinal images, but a world of objects that move and change in a coherent manner. Such stability, across the constant retinal changes, is called perceptual constancy. Perception of an object's real shape regardless of changes to its orientation is called shape constancy, and size constancy refers to the fact that we see an object as the same size regardless of its distance from us. If these constancies were not present in infant perception, the visual world would be extremely confusing, perhaps approaching James's "blooming, buzzing confusion," and they are a necessary prerequisite for many other types of perceptual organization. However, recent experiments have given clear evidence that these constancies are present at birth, and these are discussed next.

In a study of size constancy, Slater, Mattock, and Brown (1990) used preferential looking (PL) and familiarization procedures. A newborn infant being tested in a size constancy experiment is shown in Figure 1.4. In the PL experiment they presented pairs of cubes of different sizes at different distances, and it was found that newborns preferred to look at the cube which gave the largest retinal size, regardless of its distance or its real size. These findings are convincing evidence that newborns can base their responding on retinal size alone. However, in the second experiment each infant viewed either a small cube or a large cube during familiarization trials: each infant was exposed to the same-

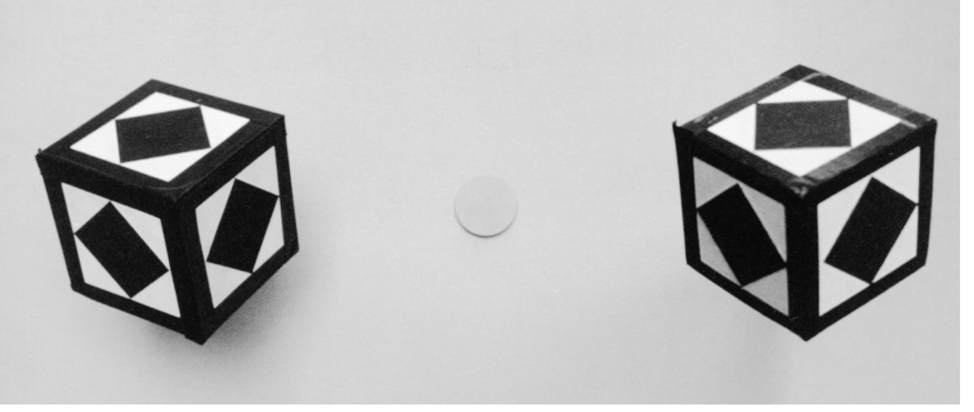

Figure 1.5 The stimuli shown to the infants on the post-familiarization test trials. This photograph, taken from the babies' viewing position, shows the small cube on the left at a distance of 30.5 cm, and the large cube on the right at a distance of 61 cm.

sized object shown at different distances on each trial. After familiarization, the infants were shown both cubes side by side, the small cube nearer and the large cube farther, such that their retinal images were the same size (Figure 1.5). The infants looked longer at the cube they were not familiarized with (consistent with the novelty preferences commonly observed in habituation studies). This indicates that the neonates differentiated the two cube sizes despite the similarities of the retinal sizes, and abstracted the familiar cube's real size over changes in distance.

Slater and Morison (1985) described experiments on shape constancy and slant perception and obtained convincing evidence both that newborn infants detect, and respond systematically to, changes in objects' slants, and also that they could respond to an object's real shape, regardless of its slant. Their results demonstrate that newborn babies have the ability to extract the constant, real shape of an object that is rotated in the third dimension: that is, they have shape constancy.

The findings of these studies demonstrate that shape and size constancy are organizing features of perception that are present at birth. E. J. Gibson (1969, p. 366) seemed to anticipate these findings:

> I think, as is the case with perceived shape, that an object tends to be perceived in its true size very early in development, not because the organism has learned to correct for distance, but because he sees the object as such, not its projected size or its distance abstracted from it.

Form Perception

The terms "figure," "shape," "pattern," and "form" are often used interchangeably, and as long ago as 1970 Zusne (p. 1) commented that "Form, like love, is a many-splendored thing . . . there is no agreement on what is meant by form, in spite of the tacit agreement

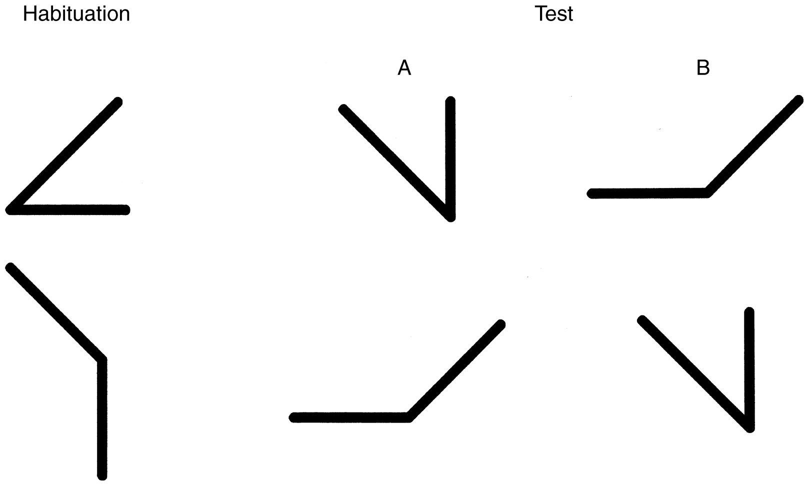

Figure 1.6 Habituation and test stimuli used in experiments on form perception by Cohen and Younger (1984) and Slater, Mattock, Brown, and Bremner (1991). Half the infants were habituated to the acute angle (upper left), half to the obtuse angle.

that there is." However, the most often used stimuli in studies of form perception are static, achromatic, two- or three-dimensional figures with easily detectable contours that can stand as figures in a figure–ground relationship, and it is primarily with reference to these that most theories of form perception have been concerned.

One of the most intractable issues in the study of form perception in early infancy is whether or not such figures or patterns are innately perceived as parts or as wholes. This can be illustrated with respect to the newborn infant's perception of simple geometric shapes. We know that newborns discriminate easily between the outline shapes of simple geometric forms such as a square, circle, triangle, and cross, but the basis of the discrimination is unclear since these shapes differ in a number of ways, such as the number and orientation of their component lines, and, as was mentioned earlier, newborns can discriminate on the basis of orientation alone.

One experiment which suggests that there is a change in the way form is perceived in early infancy was by Cohen and Younger (1984). They tested 6- and 14-week-old infants with simple stimuli, each consisting of two connected lines which made either an acute (45°) or an obtuse (135°) angle, similar to those shown in Figure 1.6. Following habituation they found that the 6-week-olds responded to a change in the orientation of the lines (where the angle remained unchanged, test stimulus A in Figure 1.6), but not to a change in angle alone (test stimulus B), while the 14-week-olds did the opposite in that they recovered attention to a change in angle, but not to a change in orientation. These findings suggest that 4-month-olds are able to perceive angular relationships, and hence have some degree of form perception, but suggest that form perception in infants 6 weeks and younger may be dominated by attention to lower-order variables such as orientation. However, an experiment by Slater, Mattock, Brown, and Bremner (1991, Experiment 2) used these stimuli and found that, with different conditions of testing, newborn infants can process the relationship between two line segments, that is, the angle, independently of its orientation. In this experiment each infant was shown either an obtuse or an acute angle, but the angle changed its orientation on each of six familiarization trials. After this familiarization period the infants were given test trials with the two angles, with each in a different orientation than any shown earlier, and they reliably looked longer at the novel angle. One interpretation of these findings is that newborn infants are able to respond both to low-order variables of stimulation, such as orientation, and also to higher-order variables, such as form (i.e., angles), and that the variable to which they respond depends on the experimental manipulation (but see Cohen, in Slater, Mattock, Brown, and Bremner, 1991, p. 405, for a different interpretation).

All visual stimuli are stimulus compounds in that they contain separate features that occur at the same spatial location, and which the mature perceiver "binds together" as a whole. With such an ability we see, for example, a green circle and a red triangle, while without it we would see greenness, redness, circularity, and triangularity as separate stimulus elements. Evidence suggests that newborn infants perceive stimulus compounds. In an experiment by Slater, Mattock, Brown, Burnham, & Young (1991) newborns were familiarized, on successive trials, to two separate stimuli. For half the infants these were a green vertical stripe and a red diagonal stripe; the other babies were familiarized to green diagonal and red vertical stripes. In the former case there are two novel combinations, these being green diagonal and red vertical, and on post-familiarization test trials the babies were shown one of the familiar compounds paired with one of the novel ones, and they showed strong novelty preferences. Note that the novel compounds consisted of stimulus elements that the babies had seen before (green, red, diagonal, vertical), and the novelty preferences are therefore clear evidence that the babies had processed and remembered the color/form compounds shown on the familiarization trials.

Subjective Contours and Gestalt Organizational Principles

Many organizational principles contribute to the perceived coherence and stability of the visual world. As discussed above, shape and size constancy are present at birth, as is some degree of form perception. Other types of visual organization have been found in young infants, and by way of illustration two of these are discussed here: subjective contours and Gestalt principles.

Subjective contours are contours that are perceived "in the absence of any physical gradient of change in the display" (Ghim, 1990). Such contours were described in detail by Kanizsa (1979) and the Kanizsa square is shown in Figure 1.7: the adult perceiver usually "completes" the contours of the figures, despite the fact that the contours are physically absent. Convincing evidence that 3- and 4-month-old infants perceive subjective contours was provided by Ghim (1990), who described a series of experiments leading to the conclusion that the infants perceived the complete form when viewing the subjective contour patterns.

One of the main contributions of the Gestalt psychologists was to describe a number of ways in which visual perception is organized. Quinn, Burke, and Rush (1993) reported evidence that 3-month-old infants group patterns according to the principle of similarity, or proximity. Two of the stimuli they used are shown in Figure 1.8. Adults reliably group

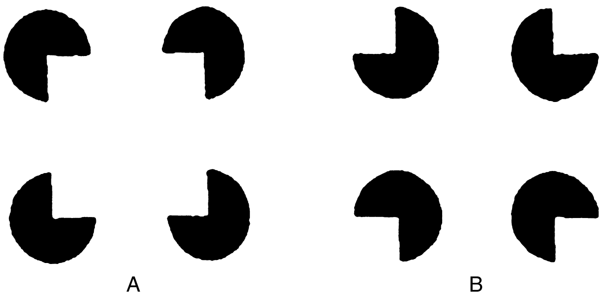

Figure 1.7 Pattern A (a Kanizsa square) produces subjective contours and is seen as a square. Pattern B contains the same four elements but does not produce subjective contours.

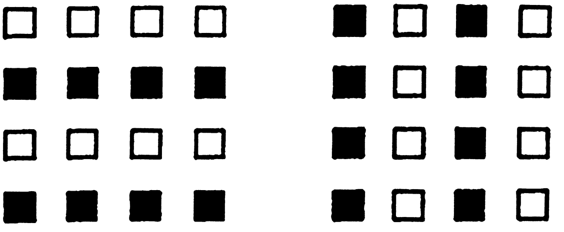

Figure 1.8 Stimuli used by Quinn et al. (1993) with 3-month-olds and by Farroni et al. (2000) with newborns. Infants, like adults, group by similarity and perceive the pattern on the left as rows, and that on the right as columns.

the elements of such stimuli on the basis of lightness (or brightness) similarity and represent the figure on the right as a set of columns, and the other as a set of rows. Three-month-olds do the same, in that those habituated to the columns pattern generalize to vertical lines and prefer (perceive as novel) horizontal lines, while those habituated to the rows prefer the novel vertical lines. In recent experiments, using similar stimuli, Farroni, Valenza, Simion, and Umilta (2000) found that newborn infants also group by similarity.

Quinn, Brown, and Streppa (1997) describe experiments using an habituation – novelty testing procedure, to determine if 3- and 4-month-old infants can organize visual patterns according to the Gestalt principles of good continuation and closure. The stimuli they used are shown in Figure 1.9. Following familiarization to pattern (a) in Figure 1.9, tests revealed that the infants parsed the pattern into a square and teardrop (b) rather than into the "less-good" patterns shown in (c): that is, they had parsed the familiarized figure into the two separate shapes of a square and a teardrop in the same way that adults do.

Overview

The above is just a sample of the many studies which demonstrate that young infants organize the visually perceived world in a similar manner to that of adult perceivers. But

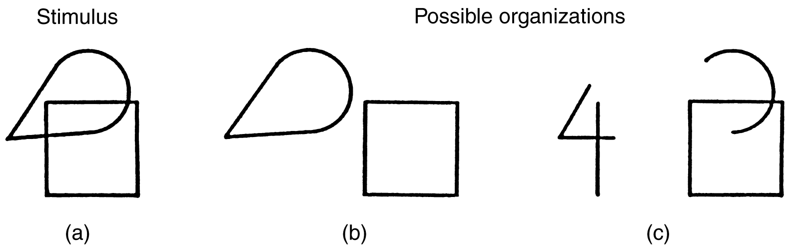

Figure 1.9 Patterns used by Quinn et al. (1997).

the newborn and young infant's world is very different from ours: "It must certainly lack associations, meaning and familiarity" (Gordon, 1997, p. 82). In the next two sections the possibility of innate (or prefunctional) representations that might guide early learning, and some of the ways in which perception is affected and changed by experience and learning in infancy, are discussed.

Is there an Innate Representation of the Human Face?[1]

Several lines of evidence converge to suggest that newborn infants come into the world with some representation of faces. Goren, Sarty, and Wu (1975) and Johnson and Morton (1991) present evidence that newborn infants are more likely to track (follow with their eyes) face-like patterns than non-face-like patterns. Johnson and Morton argue for the existence of an innate face-detecting device they call "Conspec" (short for conspecifics), which "perhaps comprises just three dark patches in a triangle, corresponding to eyes and mouth" (Pascalis et al., 1995, p. 80), and which serves to direct the newborn infant's visual attention to faces.

Imitation

Other evidence suggests that the newborn infant's hypothesized facial representation might be more detailed than simply a template that matches three dots. In particular it has been demonstrated that newborn (and older) infants will imitate a variety of facial gestures they see an adult model performing. One of the first published reports of imitation by newborn and older infants was by Meltzoff and Moore (1977), and there are now many reports of such imitation (e.g., Field, Woodson, Greenberg, & Cohen, 1982; Meltzoff & Moore, 1984, 1992, 1994, 1997; Reissland, 1988). Meltzoff (1995) suggests that "newborns begin life with some grasp of people" (p. 43) and that their ability to recognize when their facial behavior is being copied implies that "there is some representation of their own bodies" (p. 53). Infants can see the adult's face, but of course they cannot see their own. This means that in some way they have to match their own, unseen but felt, facial movements with the seen, but unfelt, facial movements of the adult. Meltzoff and Moore (1997, 2000) propose that they do this by a process of "active intermodal matching" (AIM).

A fundamental question is, "What is the motive for imitation in the newborn?" No man, and no baby, is an island, and one suggestion is that babies are born with a deep-seated need to communicate (Kokkinaki & Kugiumutzakis, 2000; Kugiumutzakis, 1993). A complementary interpretation is offered by Meltzoff and Moore (1992, 1994), who claim that imitation is an act of social cognition which serves to help the infant identify, understand, and recognize people: "infants use the non-verbal behavior of people as an identifier of who they (the people) are and use imitation as a means of verifying this identity" (1992, p. 479).

Infants Prefer Attractive Faces

Several experimenters have found that infants prefer to look at attractive faces when these are shown paired with faces judged by adults to be less attractive (e.g., Langlois, Ritter, Roggman, & Vaughn, 1991; Langlois et al., 1987; Samuels, Butterworth, Roberts, & Graupner, 1994; Samuels and Ewy, 1985). The "attractiveness effect" seems to be robust in that it is found for stimulus faces that are infant, adult, male, female, and of two ethnic groups (African American and Caucasian), and babies also preferred attractive to symmetrical faces when these two dimensions were varied independently. The effect has recently been found with newborn infants, who averaged less than three days from birth at the time of testing (Slater, Bremner, et al., 2000; Slater, Quinn, Hayes, & Brown, 2000; Slater et al., 1998).

A frequently expressed interpretation of the attractiveness effect is in terms of prototype formation and a cognitive averaging process. The origins of this interpretation can be traced back to more than a hundred years ago. In the nineteenth century Charles Darwin received a letter from Mr. A. L. Austin of New Zealand (Galton, 1907, p. 227). The letter read:

> Although a perfect stranger to you, and living on the reverse side of the globe, I have taken the liberty of writing to you on a small discovery I have made in binocular vision in the stereoscope. I find by taking two ordinary *carte-de-visite* photos of two different persons' faces, the portraits being about the same sizes, and looking about the same direction, and placing them in a stereoscope, the faces blend into one in a most remarkable manner, producing in the case of some ladies' portraits, in every instance, a decided improvement in beauty.

Darwin passed the discovery to his half cousin, Francis Galton, who confirmed the effect. Galton went further and was the first scientist to average faces, which he did photographically by underexposing each individual picture. In recent times such averaging can be done by computer, and the resulting "average" or prototypical face is typically seen as more attractive than the individual faces that combine to produce it. For this reason, averageness has been claimed to be an important ingredient of attractiveness (Langlois & Roggman, 1990). According to this interpretation, therefore, attractive faces are seen as more "face-like" because they match more closely the prototype that infants have formed from their experience of seeing faces: thus, "Infants may prefer attractive or prototypical faces because prototypes are easier to classify as a face" (Langlois & Roggman, 1990, p. 119). It is possible that newborn infants' preferences for attractive faces result from an innate representation of faces that infants bring into the world with them: Langlois and Roggman (1990) discuss the possibility of an innate account for attractiveness preferences. Alternately, it is possible that even the newborn's preference for attractive faces is a preference for an image similar to a composite of the faces they have seen in the few hours from birth prior to testing. An evolutionary account of attractiveness preferences is offered by Etcoff (2000).

Overview

It seems now to be reasonably well agreed that "there does seem to be some representational bias . . . that the neonate brings to the learning situation for faces" (Karmiloff-Smith, 1996, p. 10). This representational bias is likely to be something more elaborate than simply a tendency to attend to stimuli that possess three blobs in the location of eyes and mouth ("Conspec"). This possibility is suggested by newborn infants' ability to imitate the facial gestures produced by the first face they have ever seen (Reissland, 1988), and also, perhaps, by newborn infants' preferences for attractive faces. It is perhaps likely that experiences *in utero* (for example, proprioceptive feedback from facial movements) contribute to the newborn infant's representation of faces, which might therefore result from innate evolutionary biases, in interaction with prenatal experiences. Meltzoff and Moore (1998, p. 229) offer the premise that "evolution has . . . bequeathed human infants . . . with initial mental structures that serve as 'discovery procedures' for developing more comprehensive and flexible concepts."

Early Experience and Learning

Infants learn rapidly about their visually encountered world: as Karmiloff-Smith (1996, p. 10) has put it, "At birth visual processing starts with a vengeance." This rapid learning is apparent in the ease with which even newborn infants will habituate to visual stimuli and subsequently recover attention to novelty. In this section some clear examples of early visual learning in infancy are discussed, under the headings of face perception, intermodal perception, and perception of object segregation, and unity.

Face Perception

This representational bias for faces discussed in the previous section ensures that newborn infants have a predisposition to attend to faces, and it is clear that soon after birth they learn to distinguish between individual faces, form prototypes of faces they have seen only briefly, and recognize faces across various transformations (such transformations as size changes and a change from facing straight ahead to half profile) (Bushnell, Sai, & Mullin, 1989; Field, Cohen, Garcia, & Greenberg, 1984; Walton, Armstrong, & Bower, 1997, 1998; Walton, Bower, & Bower, 1992). Apparently, this recognition is not dependent solely on facial features. The effect disappears if the women's hairlines are covered with a scarf (Pascalis et al., 1995). Thus, attention to outer contours seems to contribute to neonates' face-recognition abilities.

Such remarkable early learning might result from an innately endowed face-specific learning mechanism (e.g., Farah, Rabinowitz, Quinn, & Liu, 2000; Nelson, 2001), or it might be a product of a more general pattern-processing system that assists the infant in learning about complex visual stimuli.

Intermodal Perception

Most of the objects and events that we experience are intermodal in that they provide information to more than one sensory modality. Such intermodal information can be broadly categorized into two types of relation, amodal and arbitrary. Amodal perception is where two (or more) senses provide information that is equivalent in one or more respects, and many types of amodal perception have been demonstrated in early infancy. Newborn infants reliably turn their heads and eyes in the direction of a sound source, indicating that spatial location is given by both visual and auditory information (Butterworth, 1983; Muir & Clifton, 1985; Wertheimer, 1961). One-month-olds demonstrate cross-modal matching by recognizing a visual shape (a pacifier) that had previously been experienced tactually by sucking, indicating that the shape is coded both tactually and visually (Meltzoff & Borton, 1979). By four months infants are sensitive to temporal synchrony specified intermodally in that they detect the common rhythm and duration of tones and flashing lights (Lewkowicz, 1986). Four-month-olds also detect and match appropriately the sounds made either by a single unitary element or by a cluster of smaller elements (Bahrick, 1987, 1988). Thus, there is evidence that infants, from birth, perceive a wide range of invariant amodal relations.

Many intermodal events give both amodal and arbitrary information. For instance, when a person speaks the synchrony of voice and mouth provides amodal information, whereas the pairing of the face and the sound of the voice is arbitrary (in the sense that there is nothing in the face that specifies tone of voice, etc.). In several publications Bahrick (e.g., 1987, 1988, 1992, 2000; Bahrick & Pickens, 1994) has provided strong evidence that learning about arbitrary intermodal relations is greatly assisted if there is accompanying amodal information: "detection of amodal invariants precedes and guides learning about arbitrary object–sound relations by directing infants' attention to appropriate object–sound pairings and then promoting sustained attention and further differentiation" (Bahrick & Pickens, 1994, p. 226).

There is evidence that newborn babies are easily able to learn arbitrary intermodal relations, but only if the intermodal stimuli are accompanied by amodal information which specifies that they "go together." Such amodal information can include spatial co-location (sight and sound are found at the same place), temporal synchrony (lips and voice are synchronized), temporal microstructure (a single object striking a surface produces a single impact sound, but a compound object, consisting of several elements, will produce a more complex, prolonged sound). Morrongiello, Fenwick, and Chance (1998) found that newborn infants learned toy–sound pairs when the two stimuli were spatially co-located, but not when they were presented in different locations. Slater, Quinn, Brown, and Hayes (1999) tested newborn infants in two conditions. In their *auditory-contingent* condition 2-day-old infants were familiarized to two alternating visual stimuli (differing in color and orientation), each accompanied by its "own" sound. The spatially located sound was presented only when the infant looked at the visual stimulus – when the infant looked away the sound stopped. Thus, presentation of the sound was contingent upon the infant looking. In their *auditory-noncontingent* condition the sound was continuously presented, independently of whether the infant looked at the visual stimulus. They found that their newborn infants learned the arbitrary auditory–visual associations when the amodal *contingent* information was present, but not when it was absent. These findings give strong support to Bahrick's views, mentioned earlier. It is clear that rapid learning about intermodal events occurs from birth, and that the presence or absence of amodal information acts both as a powerful facilitator and a constraint on learning. It is of interest to note that when the mother speaks to her infant the amodal information of temporal synchrony of voice and lips is quite likely to facilitate learning to associate her face and voice, and it seems likely that this learning occurs very soon after birth.

Perception of Object Segregation, and Unity

The visual world that we experience is complex, and one problem confronting the young infant is knowing how to segregate objects, and knowing when one object ends and another begins. Sometimes changes to color, contour, contrast, etc., are found within a single object. For example, many animals have stripes, spots, changes to coloring, etc.; people wear different-colored clothing, and there are natural color and contrast changes, perhaps from hair to forehead, from eyes to face, and so on, but these changes of course are all part of the same person.

Sometimes, similar appearance is found for different objects, as when two or more similar objects are perceived. Thus, there is no simple rule that specifies that an abrupt or gradual change in appearance indicates one or more objects. This means that the segregation of surfaces into objects is an important problem confronting the infant, and many of the rules that specify object composition and segregation have to be learned from experience. Object *segregation* is when the perceptual information indicates that two or more objects are present, and object *unity* is where we appreciate that there is only one object, despite breaks in the perceptual display: an example of the latter is where parts of an object are partly occluded by (a) nearer object(s).

A clear difference has been found in infants' perception of *object unity* in the age range birth to 4 months. In a series of experiments on infants' understanding of partly occluded objects Kellman and his colleagues (Kellman & Spelke, 1983; Kellman, Spelke, & Short, 1986) habituated 4-month-olds to a stimulus (usually a rod) that moved back and forth behind a central occluder, so that only the top and bottom parts of the rod were visible (as in the upper part of Figure 1.10). On the post-habituation test trials the infants recovered attention to two rod pieces, but not to the complete rod (shown in the lower part

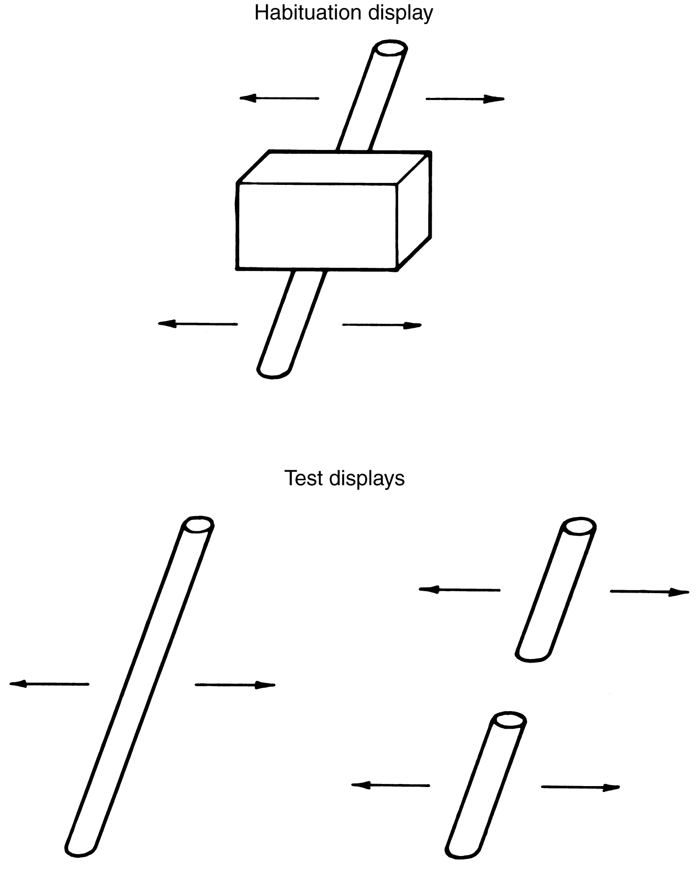

Figure 1.10 Habituation and test displays shown to infants to test perception of object unity. During habituation the rod, and during test trials the rod and rod parts, moved back and forth undergoing common motion.

of Figure 1.10), suggesting that they had been perceiving a complete rod during habituation and that the rod pieces were novel. However, when newborn babies have been tested with similar displays they look longer on the test trials at the complete rod (Slater, Johnson, Brown, & Badenoch, 1996; Slater, Johnson, Kellman, & Spelke, 1994; Slater, Morison, et al., 1990). Thus, neonates appear not to perceive partly occluded objects as consisting of both visible and nonvisible portions. Rather, they seem to respond only to what they see directly.

The difference in the response patterns of newborn and 4-month-old infants suggests that some period of development is necessary for perception of object unity to emerge in infants. Johnson and his colleagues (Johnson & Aslin, 1995; Johnson & Nanez, 1995) presented two-dimensional (computer-generated) rod-and-occluder displays, similar to the habituation display shown in Figure 1.10, to 2-month-olds. Johnson and Nanez (1995) found that, following habituation, the infants did not show a preference for either of the test stimuli, suggesting that they were perhaps not fully capable of perceiving object unity. Johnson and Aslin (1995) tested the hypothesis that "with additional visual information, infants at this young age would be more likely to perceive the unity of the rod parts" (Johnson, 1997, p. 10). They did this by testing their infants in three conditions, in each of which more of the rod was shown behind the occluder. In one of these conditions the occluder was simply made smaller in height; in another, a vertical gap was placed in the box; in the third, the occluder contained gaps. In all of these conditions the 2-month-olds now responded like 4-month-olds – that is, they showed preferences for the broken rod on the test trials, thereby indicating early perception of object unity. Thus, it appears that an understanding of the completeness, or unity, of partly occluded objects begins around two months from birth.

The young infant's limitations have been confirmed by others, in studies of *object segregation.* Spelke and her colleagues (e.g., Kestenbaum, Termine, & Spelke, 1987; Spelke, Breinlinger, Jacobson, & Phillips, 1993) have found that 3-month-olds interpret displays in which two objects are adjacent and touching as being a single unit, even though the objects may be very different in their features. Needham and Baillargeon (1998) showed 4-month-olds a stationary display consisting of a yellow cylinder lying next to, and touching, a blue box, and presented them with two test displays. In both events a gloved hand came into view, grasped the cylinder, and moved it to one side, but in one, the move apart condition, the box remained where it was, while in the other, the move together condition, the box moved with the cylinder. On these test trials the 4-month-olds looked about equally at the two test events, suggesting that they were uncertain whether the cylinder and box were one or two separate units. Needham and Baillargeon found that if the infants saw either the box or the cylinder alone for as little as 5 or 15 seconds, these brief exposures were sufficient to indicate to the infants that the cylinder-and-box display consisted of two objects.

Needham and Baillargeon (1997) investigated conditions under which 8-month-olds detect objects as separate or interconnected. They found that when the infants saw two identical yellow octagons standing side by side they expected them to be connected: on test trials the infants appeared surprised (as measured by increased looking) when the octagons moved apart, but not when they moved together. Needham and Baillargeon found that this expectation could be readily changed by experience: a nice additional finding was that a prior demonstration that a thin blade could be passed between the identical octagons at the point of contact led the infants to expect them to be two objects. When the objects shown the infants were a yellow cylinder and a blue box the infants appeared surprised when the objects moved *together*, but not when they moved apart. These findings are a clear demonstration that when the touching objects were identical 8-month-olds expected them to be one object, but when they were different in shape and color they expected them to be two objects.

The developmental story seems to be as follows. In the first two months from birth infants gradually learn about the continued existence of the unseen parts of partly occluded objects, and also come to understand the continued existence of unseen objects (Baillargeon, 1987). In terms of object segregation the young infant applies the rule "adjacency (touching) = a single unit/object"; by 4 months infants are uncertain, and experience plays a critical role in assisting them to parse the events they encounter. By 8 or 10 months the rule "different features = different objects" seems to be applied consistently, and has presumably been learned, or acquired, as a result of experience. One emerging theme from the literature is that very brief experiences can change infants' understanding of particular displays.

Emerging Questions, Paradigms, Issues

As research into infant visual perception has progressed there has become less of a reliance on the "grand theories" that were dominant in the early part of the twentieth century. Many theoretical views have emerged which deal with specific areas of development, and these views have often given rise to lively debates and have inspired critical experiments. The aim in this section is briefly to discuss three such areas that are highly interrelated: the relationship between neural structures and visual development; the role of action in visual development; early representation and thinking.

The Relationship between Neural Structures and Visual Development

Many different neural pathways are developing in the first year from birth (and later!), and it is a truism to state that perceptual and conceptual development are constrained and facilitated by their development. There are now many theoretical views which attempt to understand the relationship between neural, perceptual, and cognitive growth. Some of the issues debated include: the role of subcortical and cortical mechanisms in early visual development; hemispheric specialization and its role in face perception; the development of a ventral "what" pathway and its role in object identification and visual recognition, and a dorsal "where" or "how" pathway involved in visually guided action and spatial location (e.g., Farah et al., 2000; Milner & Goodale, 1995; Nelson, 2001); the development of the frontal cortex and its role in problem solving. Space does not permit discussion of these and other issues. An excellent introduction to the recent subdiscipline of developmental cognitive neuroscience is given by Johnson (1997).

The Role of Action in Visual Development

All spatially coordinated behaviors, such as visual tracking, visually locating an auditory source, reaching, sitting, crawling, walking, require that action and perceptual information are coordinated. In an excellent review of this topic Bertenthal (1996) quotes J. J. Gibson: "We must perceive in order to move, but we must also move in order to perceive." It has become clear that newborn infants perform many actions that are regulated by perceptual information. These include visual tracking, orienting to sounds, and hand to mouth coordination. However, while perception and action appear coordinated from birth these systems clearly develop as infancy progresses, and new couplings appear. For example, Campos, Bertenthal, and Kermoian (1992) reported that prelocomotor infants show no fear, or wariness, of heights, whereas age-matched crawling infants of the same age showed a significant amount of fear. It seems that experience with crawling changes infants' sensitivity to depth, objects, and surfaces: a detailed account and synthesis of the role of locomotor experiences in changing infants' perceptual, social, and cognitive development is given by Campos et al. (2000). Several researchers have speculated on the relation between perception and action. Bremner (1997) suggests that "development in infancy is very much to do with the formation of links between pre-existing objective perception and emerging action, so that knowledge of the world implicit in perception eventually becomes explicit knowledge in the sense that it can be used to guide action."

Several researchers have found evidence of precocious perceptual abilities in young infants. For example, newborn infants have size and shape constancy; infants as young as 3 months can represent the continued existence of invisible objects, and appear to know that solid objects should not pass through each other; 2–4-month-old infants perceive object unity in that they are aware that a partly occluded object is connected or complete behind the occluder. These findings appear to be in contradiction to Piaget's view, which is that these abilities develop only gradually over infancy, after extensive experience of observing and manipulating objects. For example, he described several observations showing how his own children appeared to acquire concepts of size and shape constancy by observing the effects of objects being moved towards and away from them (Piaget, 1954, Observations 86–91). There are at least three possible resolutions to these contradictory claims, all of which appear in the literature. One is simply to argue that Piaget was wrong. A second is to follow Bremner and make the distinction between implicit (perceptual) and explicit (in action) knowledge. A third, conceptually related, argument is to suggest that in the perception experiments the infant is a "couch potato" and that "the methods used for studying young infants are inadequate for revealing all of the knowledge and mental processes that are necessary for problem solving." In addition to perceptual abilities, "Problem solving also involves coordinating, guiding, monitoring, and evaluating a sequence of goal-directed actions" (Willatts, 1997, pp. 112, 113).

Early Representation and Thinking

Several researchers have argued that infants, from a very early age, possess a core of physical knowledge, and they also make use of active representations to reason with this knowledge. For example, newborn infants' ability to imitate facial gestures suggests that they have some innately specified representation of faces. With respect to the physical world, young infants appear to have knowledge about basic principles such as solidity, causality, trajectory, number, gravity, support, and so on. Research that demonstrates this understanding typically presents infants with "possible" and "impossible" events, where the latter violate one or other physical principle. When the infants look longer at the "impossible" event this is interpreted in terms of the infant *representing* the characteristics (or, e.g., continued existence) of the object(s), *reasoning* about the physical world, *understanding* the physical principle being tested, and being *surprised* at the violation. All the italicized words are characteristics of a conceptual system, and suggest that infants possess considerable physical knowledge from a very early age. Currently, however, these claims are highly controversial (see chapter 4). Bogartz, Shinskey, and Speaker (1997), Haith (1998), and Rivera, Wakeley, and Langer (1999) are among those who argue that these sorts of interpretations are too rich, and imbue young infants with too much conceptual ability. Haith argues that "Almost without fail we can account for infants' longer looking at an inconsistent or impossible event . . . in terms of well-established perceptual principles – novelty, familiarity, salience, and discrepancy" (p. 173). These conclusions and reinterpretations, of course, have been challenged (e.g., Spelke, 1998), and Meltzoff & Moore (1998, p. 201) "hypothesize that a capacity for representation is the starting point for infant development, not its culmination."

Conclusions

In the first section of this chapter evidence was presented suggesting that scanning abilities, acuity, contrast sensitivity, and color discrimination are limited in neonates. However, as Hainline and Abramov (1992, pp. 40–41) put it, "While infants may not, indeed, see as well as adults do, they normally see well enough to function effectively in their roles as infants." Thus, despite their sensory limitations, it is clear that newborn infants have several means with which to begin to make sense of the visual world. The visual cortex, while immature, is functioning at birth, and it seems to be the case that newborn infants possess at least rudimentary form perception. Newborn infants can clearly remember what they see, and they demonstrate rapid learning about their perceived world.

One prerequisite for object knowledge is distinguishing proximal from distal stimuli. The proximal stimulus is the sensory stimulation – in this case, the pattern of light falling on the retina. The distal stimulus consists of what is represented by the pattern of stimulation – the object itself. Neonates distinguish proximal from distal stimuli when they demonstrate size and shape constancy: the object is perceived accurately, despite changes to its retinal image. The picture of visual perception in early infancy that is emerging is complex: some aspects of visual perception are very immature, whereas others appear to be remarkably advanced at birth. Several lines of evidence converge to suggest that infants are born with an innate preference for, and representation of, the human face. It is clear that the young infant's visual world is, to a large extent, structured and coherent as a result of the intrinsic organization of the visual system.

However well organized the visual world of the young infant may be, it lacks the familiarity, meaning, and associations that characterize the world of the mature perceiver. Inevitably, some types of visual organization take time to develop. An appreciation of the underlying unity, coherence, and persistence of occluded objects is not present at birth, and a proper understanding of the physical properties of objects emerges only slowly as infancy progresses. As development proceeds, the innate and developing organizational mechanisms are added to by experience, which assists the infant in making sense of the perceived world.

Note

1 The term "innate" refers to behaviors and abilities that are inherited and not appreciably affected by experience. Thus, visual abilities that are present in the newborn infant are likely to be innate. In the case of face perception it is possible that proprioceptive feedback from its own facial and body movements *in utero* contributes to the newborn infant's facial representation. An alternative term, prefunctional, avoids the potential pitfalls of calling something "innate," but for present purposes the term innate is used without any assumption that we know how the ability(ies) originated.

Related Topics and Further Reading

Research into visual perception is carried out by many thousands of researchers, and in this chapter it is only possible to give a brief outline of its development in infancy. Topics that have either not been covered, or have not been discussed in any depth, include motion perception, neural development, abnormalities of development, intersensory perception, categorization, and perception of causality. Additional readings which deal with these and other topics in more detail are:

Atkinson, J. (2000). *The developing visual brain.* Oxford: Oxford University Press.
Kellman, P. J., & Arterberry, M. E. (1998). *The cradle of knowledge: Development of perception in infancy.* Cambridge, MA and London: MIT Press.
Lewkowicz, D. J. & Lickliter, R. (1994). *The development of intersensory perception: Comparative perspectives.* Hillsdale, NJ: Lawrence Erlbaum Associates.
Simion, F. & Butterworth, G. (Eds.). (1998). *The development of sensory, motor and cognitive capacities in early infancy.* Hove: Psychology Press.
Slater, A. (Ed.). (1998). *Perceptual development: Visual, auditory and speech perception in infancy.* Hove: Psychology Press.
Vital-Durand, F., Atkinson, J., & Braddick, O. J. (Eds.). (1996). *Infant vision.* Oxford, New York, and Tokyo: Oxford University Press.

References

Arterberry, M. E., & Yonas, A. (2000). Perception of three-dimensional shape specified by optic flow by 8-week-old infants. *Perception and Psychophysics*, *62*, 550–556.
Aslin, R. N. (1981). Development of smooth pursuit in human infants. In D. F. Fisher, R. A. Monty, & J. W. Senders (Eds.), *Eye movements: Cognition and visual perception* (pp. 31–51). Hillsdale, NJ: Erlbaum.
Aslin, R. N., & Salapatek, P. (1975). Saccadic localization of visual targets by the very young human infant. *Perception and Psychophysics*, *17*, 293–302.
Atkinson, J. (1984). Human visual development over the first six months of life: A review and a hypothesis. *Human Neurobiology*, *3*, 61–74.
Atkinson, J. (2000). *The developing visual brain.* Oxford: Oxford University Press.
Atkinson, J., & Braddick, O. (1989). Development of basic visual functions. In A. Slater & G. Bremner (Eds.), *Infant development* (pp. 7–41). Hove and Hillsdale, NJ: Erlbaum.
Atkinson, J., Hood, B. M., Wattam-Bell, J., Anker, S., & Trickelbank, J. (1988). Development of orientation discrimination in infancy. *Perception*, *17*, 587–595.

Bahrick, L. E. (1987). Infants' intermodal perception of two levels of temporal structure in natural events. *Infant Behavior and Development*, *10*, 387–416.
Bahrick, L. E. (1988). Intermodal learning in infancy: Learning on the basis of two kinds of invariant relations in audible and visible events. *Child Development*, *59*, 197–209.
Bahrick, L. E. (1992). Infants' perceptual differentiation of amodal and modality-specific audiovisual relations. *Journal of Experimental Child Psychology*, *53*, 197–209.
Bahrick, L. E. (2000). Increasing specificity in the development of intermodal perception. In D. Muir & A. Slater (Eds.), *Infant development: The essential readings* (pp. 119–136). Oxford and Cambridge, MA: Blackwell.
Bahrick, L. E., & Pickens, J. N. (1994). Amodal relations: The basis for intermodal perception and learning in infancy. In D. J. Lewkowicz & R. Lickliter (Eds.), *The development of intersensory perception: Comparative perspectives* (pp. 205–233). Hillsdale, NJ: Erlbaum.
Baillargeon, R. (1987). Object permanence in 3.5- and 4.5-month-old infants. *Developmental Psychology*, *23*, 655–664.
Banks, M. S., & Dannemiller, J. L. (1987). Infant visual psychophysics. In P. Salapatek & L. Cohen (Eds.), *Handbook of infant perception: Vol. 1. From sensation to perception* (pp. 115–184). London: Academic Press.
Bertenthal, B. I. (1996). Origins and early development of perception, action, and representation. *Annual Review of Psychology*, *47*, 431–459.
Bogartz, R. S., Shinskey, J. L., & Speaker, C. (1997). Interpreting infant looking. *Developmental Psychology*, *33*, 408–422.
Bower, T. G. R. (1966). The visual world of infants. *Scientific American*, *215*(6), 80–92.
Braddick, O. J., & Atkinson, J. (1983). Some recent findings on the development of human binocularity: A review. *Behavioural Brain Research*, *10*, 71–80.
Bremner, J. G. (1994). *Infancy.* Oxford: Blackwell.
Bremner, J. G. (1997). From perception to cognition. In G. Bremner, A. Slater, & G. Butterworth (Eds.), *Infant perception: Recent advances* (pp. 55–74). Hove: Psychology Press.
Bremner, G., Slater, A., & Butterworth, G. (Eds.) (1997). *Infant perception: Recent advances.* Hove: Psychology Press.
Bronson, G. W. (1974). The postnatal growth of visual capacity. *Child Development*, *45*, 873–890.
Brown, A. M., Dobson, V., & Maier, J. (1987). Visual acuity of human infants at scotopic, mesopic and photopic luminances. *Vision Research*, *27*, 1845–1858.
Bushnell, I. W. R., Sai, F., & Mullin, J. T. (1989). Neonatal recognition of the mother's face. *British Journal of Developmental Psychology*, *7*, 3–15.
Butterworth, G. E. (1983). Structure of the mind in human infancy. In L. P. Lipsitt & C. K. Rovee-Collier (Eds.), *Advances in infancy research* (pp. 1–29). Norwood, NJ: Ablex.
Campos, J. J., Anderson, D. I., Barbu-Roth, M. A., Hubbard, E. M., Hertenstein, M. J., & Witherington, D. (2000). Travel broadens the mind. *Infancy*, *1*, 149–219.
Campos, J. J., Bertenthal, B. I., & Kermoian, R. (1992). Early experience and emotional development: The emergence of wariness of heights. *Psychological Science*, *3*, 61–64.
Cohen, L. B., & Younger, B. A. (1984). Infant perception of angular relations. *Infant Behavior and Development*, *7*, 37–47.
Etcoff, N. (2000). *Survival of the prettiest: The science of beauty.* New York: Doubleday.
Farah, M. J., Rabinowitz, C., Quinn, G. E., & Liu, G. T. (2000). Early commitment of neural substrates for face recognition. *Cognitive Neuropsychology*, *17*, 117–123.
Farroni, T., Valenza, E., Simion, F., & Umilta, C. (2000). Configural processing at birth: Evidence for perceptual organisation. *Perception*, *29*, 355–372.
Field, T. M., Cohen, D., Garcia, R., & Greenberg, R. (1984). Mother–stranger face discrimination by the newborn. *Infant Behavior and Development*, *7*, 19–25.

Field, T. M., Woodson, R., Greenberg, R., & Cohen, D. (1982). Discrimination and imitation of facial expressions by neonates. *Science*, *218*, 179–181.

Galton, F. (1907). *Inquiries in human faculty and its development.* London: J. M. Dent & Sons.

Ghim, H.-R. (1990). Evidence for perceptual organization in infants: Perception of subjective contours by young infants. *Infant Behavior and Development*, *13*, 221–248.

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

Gibson, J. J. (1950). *The perception of the visual world.* Boston: Houghton Mifflin.

Gibson, J. J. (1966). *The senses considered as perceptual systems.* Boston: Houghton Mifflin.

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston: Houghton Mifflin.

Gordon, I. E. (1997). *Theories of visual perception* (2nd edn.). New York: Wiley.

Goren, C. C., Sarty, M., & Wu, P. Y. K. (1975). Visual following and pattern discrimination of face-like stimuli by newborn infants. *Pediatrics*, *56*, 544–549.

Hainline, L. (1998). The development of basic visual abilities. In A. Slater (Ed.), *Perceptual development: Visual, auditory and speech perception in infancy* (pp. 37–44). Hove: Psychology Press.

Hainline, L., & Abramov, I. (1985). Saccades and small-field optokinetic nystagmus in infants. *Journal of the American Optometric Association*, *56*, 620–626.

Hainline, L., & Abramov, I. (1992). Assessing visual development: Is infant vision good enough? In C. Rovee-Collier & L. P. Lipsitt (Eds.), *Advances in infancy research* (Vol. 7, pp. 1–43). Norwood, NJ: Ablex.

Haith, M. M. (1998). Who put the cog in infant cognition? Is rich interpretation too costly? *Infant Behavior and Development*, *21*, 167–179.

Hamer, R. D., Norcia, A. M., Tyler, C. W., & Hsu-Winges, C. (1989). The development of monocular and binocular VEP acuity. *Vision Research*, *29*, 397–408.

Hebb, D. O. (1949). *The organization of behavior*. New York: Wiley.

Held, R. (1985). Binocular vision: Behavioral and neuronal development. In J. Mehler & R. Fox (Eds.), *Neonate cognition: Beyond the blooming, buzzing confusion.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Howland, H. C., Dobson, V., & Sayles, N. (1987). Accommodation in infants as measured by photorefraction. *Vision Research*, *27*, 2141–2152.

James, W. (1890). *Principles of psychology.* New York: Henry Holt.

Johnson, M. H. (1990). Cortical maturation and the development of visual attention in early infancy. *Journal of Cognitive Neuroscience*, *2*, 81–95.

Johnson, M. H. (1997). *Developmental cognitive neuroscience.* Oxford and Cambridge, MA: Blackwell.

Johnson, M. H., & Morton, J. (1991). *Biology and cognitive development: The case for face recognition.* Oxford: Blackwell.

Johnson, S. P. (1997). Young infants' perception of object unity: Implications for development of attentional and cognitive skills. *Current Directions in Psychological Science*, *6*, 5–11.

Johnson, S. P., & Aslin, R. N. (1995). Perception of object unity in 2-month-old infants. *Developmental Psychology*, *31*, 739–745.

Johnson, S. P., & Nanez, J. E. (1995). Young infants' perception of object unity in two-dimensional displays. *Infant Behavior and Development*, *18*, 133–143.

Kanizsa, G. (1979). *Organization in vision: Essays on Gestalt perception.* New York: Praeger.

Karmiloff-Smith, A. (1996, Fall). The connectionist infant: Would Piaget turn in his grave? *SRCD Newsletter*, 1–3, 10.

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

Kellman, P. J., Spelke, E. S., & Short, K. R. (1986). Infant perception of object unity from translatory motion in depth and vertical translation. *Child Development*, *57*, 72–86.

Kestenbaum, R., Termine, N., & Spelke, E. S. (1987). Perception of objects and object boundaries by 3-month-olds. *British Journal of Developmental Psychology*, *5*, 367–383.

Kokkinaki, T., & Kugiumutzakis, G. (2000). Basic aspects of vocal imitation in infant–parent interaction during the first 6 months. *Journal of Reproductive and Infant Psychology*, *18*, 173–187.

Kugiumutzakis, G. (1993). Intersubjective vocal imitation in early mother–infant interaction. In J. Nadel & L. Camioni (Eds.), *New perspectives in early communicative development* (pp. 23–47). London and New York: Routledge.

Langlois, J. H., Ritter, J. M., Roggman, L. A., & Vaughn, L. S. (1991). Facial diversity and infant preferences for attractive faces. *Developmental Psychology*, *27*, 79–84.

Langlois, J., & Roggman, L. A. (1990). Attractive faces are only average. *Psychological Science*, *1*, 115–121.

Langlois, J. H., Roggman, L. A., Casey, R. J., Ritter, J. M., Rieser-Danner, L. A., & Jenkins, V. Y. (1987). Infant preferences for attractive faces: Rudiments of a stereoptype? *Developmental Psychology*, *23*, 363–369.

Lewkowicz, D. J. (1986). Developmental changes in infants' bisensory response to synchronous durations. *Infant Behavior and Development*, *9*, 335–353.

Marg, E., Freeman, D. N., Peltzman, P., & Goldstein, P. J. (1976). Visual acuity development in human infants: Evoked potential measurements. *Investigative Ophthalmology and Visual Science*, *15*, 150–153.

Meltzoff, A. N. (1995). Infants' understanding of people and things: From body imitation to folk psychology. In J. L. Bermudez, A. Marcel, & N. Eilan (Eds.), *The body and the self* (pp. 43–69). Cambridge, MA, and London: MIT Press.

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

Meltzoff, A. N., & Moore, M. K. (1977). Imitation of facial and manual gestures by human neonates. *Science*, *198*, 75–78.

Meltzoff, A. N., & Moore, M. K. (1984). Newborn infants imitate adult gestures. *Child Development*, *54*, 702–709.

Meltzoff, A. N., & Moore, M. K. (1992). Early imitation within a functional framework: The importance of person identity, movement, and development. *Infant Behavior and Development*, *15*, 479–505.

Meltzoff, A. N., & Moore, M. K. (1994). Imitation, memory, and the representation of persons. *Infant Behavior and Development*, *17*, 83–99.

Meltzoff, A. N., & Moore, M. K. (1997). Explaining facial imitation: A theoretical model. *Early Development and Parenting*, *6*, 179–192.

Meltzoff, A. N., & Moore, M. K. (1998). Object representation, identity, and the paradox of early permanence: Steps toward a new framework. *Infant Behavior and Development*, *21*, 201–235.

Meltzoff, A. N. & Moore, M. K. (2000). Resolving the debate about early imitation. In D. Muir & A. Slater (Eds.), *Infant development: The essential readings* (pp. 176–181). Oxford and Cambridge, MA: Blackwell.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford: Oxford University Press.

Morrongiello, B. A., Fenwick, K. D., & Chance, G. (1998). Crossmodal learning in newborn infants: Inferences about properties of auditory–visual events. *Infant Behavior and Development*, *21*, 543–553.

Muir, D. W., & Clifton, R. (1985). Infants' orientation to the location of sound sources. In G. Gottlieb & N. Krasnegor (Eds.), *The measurement of audition and vision during the first year of life: A methodological overview* (pp. 171–194). Norwood, NJ: Ablex.

Needham, A., & Baillargeon, R. (1997). Object segregation in 8-month-old infants. *Cognition*, *62*, 121–149.

Needham, A., & Baillargeon, R. (1998). Effects of prior experience on 4.5-month-old infants' object segregation. *Infant Behavior and Development*, *21*, 1–24.

Nelson, C. A. (2001). The development and neural bases of face recognition. *Infant and Child Development*, *10*, 3–18.

Pascalis, O., de Schonen, S., Morton, J., Deruelle, C., & Fabre-Grenet, M. (1995). Mother's face recognition by neonates: A replication and an extension. *Infant Behavior and Development*, *18*, 79–85.

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

Piaget, J. (1953). *The origins of intelligence in the child*. London: Routledge & Kegan Paul.

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

Quinn, P. C., Brown, C. R., & Streppa, M. L. (1997). Perceptual organization of complex visual configurations by young infants. *Infant Behavior and Development*, *20*, 35–46.

Quinn, P. C., Burke, S., & Rush, A. (1993). Part–whole perception in early infancy: Evidence for perceptual grouping produced by lightness similarity. *Infant Behavior and Development*, *16*, 19–42.

Reissland, N. (1988). Neonatal imitation in the first hour of life: Observations in Rural Nepal. *Developmental Psychology*, *24*, 464–469.

Rivera, S. M., Wakeley, A., & Langer, J. (1999). The drawbridge phenomenon: Representational reasoning or perceptual preference? *Developmental Psychology*, *35*, 427–435.

Samuels, C. A., Butterworth, G., Roberts, T., & Graupner, L. (1994). Babies prefer attractiveness to symmetry. *Perception*, *23*, 823–831.

Samuels, C. A., & Ewy, R. (1985). Aesthetic perception of faces during infancy. *British Journal of Developmental Psychology*, *3*, 221–228.

Sen, M. G., Yonas, A., & Knill, D. (2001). Development of infants' sensitivity to surface contour information for spatial layout. *Perception*, *30*, 167–176.

Slater, A. (Ed.). (1998). *Perceptual development: Visual, auditory and speech perception in infancy*. Hove: Psychology Press.

Slater, A., Bremner, J. G., Johnson, S. P., Sherwood, P., Hayes, R., & Brown, E. (2000). Newborn infants' preference for attractive faces: The role of internal and external facial features. *Infancy*, *1*, 265–274.

Slater, A., Johnson, S. P., Brown, E., & Badenoch, M. (1996). The roles of texture and occluder size on newborn infants' perception of partly occluded objects. *Infant Behavior and Development*, *19*, 145–148.

Slater, A., Johnson, S. P., Kellman, P. J., & Spelke, E. S. (1994). The role of three-dimensional depth cues in infants' perception of partly occluded objects. *Early Development and Parenting*, *3*, 187–191.

Slater, A., Mattock, A., & Brown, E. (1990). Size constancy at birth: Newborn infants' responses to retinal and real size. *Journal of Experimental Child Psychology*, *49*, 314–322.

Slater, A., Mattock, A., Brown, E., & Bremner, J. G. (1991). Form perception at birth: Cohen and Younger revisited. *Journal of Experimental Child Psychology*, *51*, 395–405.

Slater, A., Mattock, A., Brown, E., Burnham, D., & Young, A. W. (1991). Visual processing of stimulus compounds in newborn infants. *Perception*, *20*, 29–33.

Slater, A., & Morison, V. (1985). Shape constancy and slant perception at birth. *Perception*, *14*, 337–344.

Slater, A., Morison, V., & Somers, M. (1988). Orientation discrimination and cortical function in the human newborn. *Perception*, *17*, 597–602.

Slater, A., Morison, V., Somers, M., Mattock, A., Brown, E., & Taylor, D. (1990). Newborn and older infants' perception of partly occluded objects. *Infant Behavior and Development*, *13*, 33–49.

Slater, A., Quinn, P., Hayes, R., & Brown, E. (2000). The role of facial orientation in newborn infants' preference for attractive faces. *Developmental Science*, *3*, 181–185.

Slater, A., Quinn, P., Brown, E., & Hayes, R. (1999). Intermodal perception at birth: Intersensory redundancy guides newborn infants' learning of arbitrary auditory–visual pairings. *Developmental Science*, *2*, 333–338.

Slater, A., Rose, D., & Morison, V. (1984). Newborn infants' perception of similarities and differences between two- and three-dimensional stimuli. *British Journal of Developmental Psychology*, *2*, 287–294.

Slater, A., von der Schulenburg, C., Brown, E., Badenoch, M., Butterworth, G., Parsons, S., & Samuels, C. (1998). Newborn infants prefer attractive faces. *Infant Behavior and Development*, *21*, 345–354.

Sokol, S. (1978). Measurement of infant acuity from pattern reversal evoked potentials. *Vision Research*, *18*, 33–40.

Spelke, E. S. (1998). Nativism, empiricism, and the origins of knowledge. *Infant Behavior and Development*, *21*, 181–200.

Spelke, E., Breinlinger, K., Jacobson, K., & Phillips, A. (1993). Gestalt relations and object perception: A developmental study. *Perception*, *22*, 1483–1501.

Teller, D. Y. (1983). Scotopic vision, color vision, and stereopsis in infants. *Current Eye Research*, *2*, 199–210.

Vital-Durand, F., Atkinson, J., & Braddick, O. (Eds.). (1996). *Infant vision*. Oxford: Oxford University Press.

von Noorden, G. K. (1988). A reassessment of infantile esotropia. XLIV Edward Jackson Memorial Lecture. *American Journal of Ophthalmology*, *105*, 1–10.

Walton, G. E., Armstrong, E. S., & Bower, T. G. R. (1997). Faces as forms in the world of the newborn. *Infant Behavior and Development*, *20*, 537–543.

Walton, G. E., Armstrong, E. S., & Bower, T. G. R. (1998). Newborns learn to identify a face in eight/tenths of a second? *Developmental Science*, *1*, 79–84.

Walton, G. E., Bower, N. J. A., & Bower, T. G. R. (1992). Recognition of familiar faces by newborns. *Infant Behavior and Development*, *15*, 265–269.

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

Willatts, P. (1997). Beyond the "couch potato" infant: How infants use their knowledge to regulate action, solve problems, and achieve goals. In G. Bremner, A. Slater, & G. Butterworth (Eds.), *Infant perception: Recent advances* (pp. 109–135). Hove: Psychology Press.

Yonas, A., Cleaves, N., & Pettersen, L. (1978). Development of sensitivity to pictorial depth. *Science*, *200*, 77–79.

Yonas, A., & Granrud, C. E. (1985). Development of visual space perception in young infants. In J. Mehler & R. Fox (Eds.), *Neonate cognition: Beyond the blooming, buzzing confusion*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Zuckerman, C. B., & Rock, I. (1957). A reappraisal of the roles of past experience and innate organizing processes in visual perception. *Psychological Bulletin*, *54*, 269–296.

Zusne, L. (1970). *Visual perception of form*. New York: Academic Press.