INTRODUCTION

What Is Perception?

Perception is the process by which animals gain knowledge about their environment and about themselves in relation to the environment. It is the beginning of knowing, and so is an essential part of cognition. More specifically, to perceive is to obtain information about the world through stimulation. The perceptual systems of animals have evolved to detect patterns of light, of sound, and of pressure on the skin that carry information about the events, things, and places in the world. This information is in the world, but it is not the events and places themselves. It is to be found in the structure of stimulation, and it specifies the world that an animal perceives. To understand perception, we must first understand what aspects of the world an animal perceives and what information specifies the things it perceives.

Perceiving is an active process; it depends on perceptual systems that pick up stimulus information. Stimulation does not simply fall passively upon a receptor surface like rain upon the ground, for the perceptual systems are more than receptor surfaces. We do not just see, for example, we look, and in the course of looking, our pupils adjust to the level of illumination, our eyes converge or diverge, we move our heads or change our position to get a better view of something, and sometimes we even put on spectacles.

If the perceptual systems are active and are adjusted constantly to optimize the information being picked up, it is obvious that perception is selective. A continuous flow of information is available in the flux of stimulation; what is actually extracted by the animal's perceptual systems is only a part of it. It is this aspect of perception that can be referred to as attention, but attending is not really separable from perceiving itself.

What Is Perceived?

A description of perception starts with the events and things in the world and proceeds to the information in stimulation that is actually picked up by the perceptual systems. Do we, then, perceive this information? Such an answer can be immediately rejected. We do not perceive stimuli or even any momentary representation of them on a receptor surface, such as a retinal image. We perceive the events and things in the world. To perceive any event or thing, the information in stimulation must correspond to it, in the sense of *specifying* it. Events and things are specified in many ways for us, for example, in light, in sound, and in pressure patterns on the surfaces of the body. These sources of energy provide information to the visual system, the auditory system, and the haptic system. But through the activity of the perceptual systems, we perceive a unitary world, not separate collections of visual, auditory, and tactile impressions. This review is organized in terms of what is in the world for humans to perceive: events, objects, places, and artifacts that represent them.

Events

What goes on in the world goes on in a continuous stream with no full stops and starts and with few displays that remain perfectly still while one contemplates them. Nor does the perceiver herself stand still. Heads containing eyes and ears and noses and vestibular organs are almost continually moving. This chapter does not focus, then, on perception of static displays but on perception of continuous happenings in the world, specified by continuously changing arrays of stimulation. These happenings are events, and they seem to have a beginning and an end, even though the information for them is continuous over time. When a perceiver observes an event, she perceives changes that occur over time as well as a persisting, underlying layout of objects and places.

Objects

The world is furnished with objects, closed surfaces that are substantial and that retain their integrity over time. Many objects, such as people, stones, and books, are detached; they are capable of moving around or being moved. Some objects are attached to immoveable surfaces, such as a tree that is fixed to the terrain. Although attached objects are not moveable, they can be walked around. Each object is perceived as a unit, a separate whole, and it has properties that are perceived as well. The unity and most of the properties of an object are specified by information in a flow of stimulation that occurs as the object participates in events.

Places

Places are segregated parts of the layout of the world at which surfaces meet one another, often forming an enclosure. Places may have vistas and paths that can be seen or walked through, walls that constitute obstacles and conceal things, a ground that can be walked on, and dropoffs that must be avoided. An animal always lives and acts in some place. After a certain age, it can move around in that place and even move out of it, but the place persists. At any given moment, the animal occupies one point of observation, but that point changes continuously as the animal moves, and it can be exchanged with the vantage point of another animal. As the animal changes its location in a layout, objects come in and out of view; they are occluded and disoccluded. Over these changes, there is information to specify the persisting layout of the environment.

Pictures

Many of the furnishings of the world are artifacts, and some of these represent the events, objects, and places of the world. Pictures are representations par excellence, and they afford a means of obtaining knowledge about the world secondhand. They are very interesting for the study of perception because of their dual character as objects and as serviceable, although imperfect, representations of real scenes and events.

The Point of View

We approach the problems and the literature of perception by beginning with the ecology of an animal, its way of life as a species, and the biological structures with which it has been endowed by nature. Every species has evolved in a habitat, and in the long course of evolution, its niche and its biological structures have developed in reciprocity with one another. The perceptual systems developed in the context of this mutual relationship. They have adapted to enable the perceiver to extract the information that he needs for survival in the kind of world he lives in, especially to extract information about the affordances of things.

Affordances are a way of talking about meaning, but a special way. The term was introduced by J. J. Gibson (1979):

> The *affordances* of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill. . . . I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment. (p. 127)

Places, objects, and events all have affordances for human animals. A floor affords support, and it can be walked on. A wall is an obstacle that affords collision, but a doorway in the wall affords walking through. A cave affords shelter from the rain, which affords getting wet. Water affords drinking, but not walking on. A screen affords hiding. A fire affords warming oneself and reading by its light. Affordance is a functional term that emphasizes the utility of some aspect of the environment for an animal (E. J. Gibson, 1982).

The properties of events, objects, and places are specified by constant, higher order relationships in the flow of stimulation, relationships that we, after J. J. Gibson (1966, 1979), call invariants. Invariants are abstract and relational. Many are also available to more than one modality, that is, the same higher order relationship may be constant over changing stimulation to the eye, the ear, and the skin. Perhaps the most familiar case of an invariant is the optical structure that persists over movements of the eyes, head, or body. As a person moves over the ground, or moves a rigid object in his hands, there is a continuous transformation of the stimulation projected to his eyes. Nevertheless, the projective properties of the optic array, such as the cross-ratio of the distances between any four collinear points, remain constant. Despite the optical flow, these projective properties are invariant and provide information about the layout of surfaces and the objects resting upon them. In this case, as in others to be described throughout this chapter, "the flow of the array does not destroy the structure beneath the flow" (J. J. Gibson, 1979, p. 310).

An animal perceives events, objects, places, and their affordances by seeking out and detecting invariants. Some mechanisms for detecting invariants are present at birth, but sensitivity to invariants increases as new perceptual and exploratory abilities mature or become modified by experience. Furthermore, the child's developing perceptual systems provide information that is increasingly accessible for new purposes. For the very young infant, perception of an affordance might guide only a limited repertoire of adaptive actions. For the older child, perception of an affordance will come to guide actions of many kinds and can even become an object of thought.

The point of view espoused in this chapter is not constructivist. We do not conceive of perception as the building of a representation of the world from a collection of elementary sensations through processes of association, inference, or assimilation to a schema. We stress, instead, that perception depends on a search for invariance in stimulation that is continually changing. An important function of perception is to search for the persisting structures and the invariants that provide information about the environment and its affordances. Perception develops not through the construction of new descriptions of the world, but through the discovery of new information about it.

EXPLORING AND ATTENDING

Over the course of development, animals gain knowledge about the events, objects, and layout of the world and of what they afford for behavior. By what means is a human infant prepared to proceed with this massive program? Human infants are far from being precocial; nature has given them little in the way of ready-to-go knowledge about the situations they will encounter in the world. But they are richly endowed with the means of finding out about the environment. Active exploration begins at birth, and exploratory skills increase with maturation and with practice. An infant's looking and listening and to some extent her feeling, smelling, and tasting are inherently coordinated for obtaining information. Furthermore, coordinated multimodal exploration, such as auditory-visual coordination, is functional very early and does not appear to depend on learning. These precoordinated systems provide a way of learning about the world at an early age, and we have seen in recent years that infants are motivated to use them actively in seeking information. From infancy to childhood, exploration appears to become more specific in its direction, more economical, and more systematic, but it has a purposeful look from the start.

The Beginnings of Information Pickup

Visual Exploration

Visual exploration provides the major means of information gathering for very young infants. Fixating high-contrast patterns, tracking moving ones, and moving the head and upper trunk to assist in localizing and following objects are all preadapted coordinated systems, imperfect but functional at birth. These exploratory activities improve rapidly during the first few months with maturation of the visual system.

Infants of 1 month reliably turn in the direction of a target by saccadic movements of the eyes when the target is introduced as far as 30° from the line of sight along horizontal and diagonal axes and as far as 10° along the vertical axis (Aslin & Salapatek, 1975). The first saccade is not very accurate: It is usually short of the target and is followed by one or more saccades of equal amplitude. Infants shift their gaze further when the target is farther away, however, showing adaptation to the target's distance. Evidence from directionally appropriate first saccades and multiple saccades following them led Aslin and Salapatek to conclude that the infants were motivated to look at the targets.

Even newborn infants shift their gaze toward the side of the field in which a peripheral target is introduced (Harris & MacFarlane, 1974). Localization of a peripheral target is swifter and occurs for a target at a greater distance if there is no central stimulus present. The probability of locating a distant peripheral target is enhanced if the central target is stationary and the peripheral one is in motion (Tronick, 1972). The effective visual field was thought to expand with age by earlier investigators (see Tronick, 1972), but no expansion was found between 1 and 7 weeks when a competing central stimulus was introduced with a peripheral one (MacFarlane, Harris, & Barnes, 1976), suggesting that selective attention to a centrally located target occurs at both ages.

Infants under 2 months do not track a moving stimulus with smooth-pursuit movements that match the velocity and direction of the stimulus; instead, following occurs in the form of a jerky series of saccadic refixations (see Salapatek & Banks, 1978). Kreminitzer, Vaughan, Kurtzberg, and Dowling (1979) observed that smooth pursuit occurred only about 15% of the time in newborn infants. Its velocity increased with target velocity up to 19°/sec. and deteriorated at faster speeds. Tracking occurs at 8 weeks when an object is displaced relative to a background, but not when the object and background move together (Harris, Cassel, & Bamborough, 1974). When an object moves against a stationary background it successively occludes texture in the background field. Occlusion and disocclusion of a stationary field provide information for differentiating objects from background surfaces.

Movements of the head in relation to a peripheral stationary target or a target moving across the field have been studied less, probably because infants have usually been observed in a supine position making head control difficult. Bullinger (1977) observed neonates seated in a chair before a white background. A flock of red wool was dangled at the infant's eye level, 70-cm distant. The object was presented at the left, right, or center for 1 min. Infants oriented head and eyes toward the object. When the object was swung in front of the infant, both head and eyes turned slowly to follow it, but the movements were jerky rather than smooth and were not well calibrated to the object's rate of motion.

Auditory-Visual Exploration

Visual exploration of sounding objects is a precoordinated system of particular interest because it provides a basis for perceiving a unified world. Does the very young infant turn head and eyes to look at a sound source and explore it visually? Evidence for innate coordination was reported by Wertheimer (1961); a newborn infant turned her eyes in the direction of a sound (a click). Other experimenters have reported different results. Butterworth and Castillo (1976) observed that newborn infants moved their eyes away from a loud click. Sound intensity may affect the direction of looking (Hammer & Turkewitz, 1975). McGurk, Turnure, and Creighton (1977) also failed to find ipsilateral eye movements to clicks in neonates. Several more recent experiments with persisting, structured sounds nevertheless have obtained results that confirm Wertheimer's (1961) earlier observation.

Mendelson and Haith (1976) used a 40-sec. presentation of human speech. It was presented laterally, and there was a stationary bar on either the same or the contralateral side of the infant's visual field. Visual scanning of the field was influenced by the speech; infants turned at first toward the sound, then away from it. The authors interpreted this as an extended search for a change in the visual field. A signal detection analysis of eye turning to the sound of a human voice saying "baby" was performed by Crassini and Broerse (1980). The infants turned toward the sound at significantly greater than chance level. The frequency of these turns was not high, but it was greater than the frequency of turns in the absence of a laterally presented sound. Alegria and Noirot (1978) reported that infants turned their heads in the direction of a human voice as well, opening their eyes as they did so.

Identification of the conditions that promote visual exploration to sounds has been extended in further experiments. Muir and Field (1978) investigated head turning toward sound (a rattle produced by shaking a plastic bottle containing popcorn) in neonates held in such a way that they could turn their heads spontaneously. All babies turned correctly on the majority of trials, appearing to investigate the locus of the shaking rattle: "They hunched their shoulders, actively pulled their heads up, turned to the side of the stimulus, and then seemed to inspect the sound source visually" (p. 432). The importance of a more continuous sound and a free-to-move head are apparent. In a further experiment, Field, DiFranco, Dodwell, and Muir (1979) presented 2½-month-old infants with a recording of a woman's voice reading poetry. Infants turned both head and eyes toward the voice. Sustained, complex, auditory stimulation again seemed to favor visual orientation. Field, Muir, Pilon, Sinclair, and Dodwell (1980) compared infants aged 1, 2, and 3 months for head and eye turning to a sound produced by shaking a popcorn-filled bottle. Infants turned reliably at 1 and 3 months, but less reliably at 2 months.

Several experiments indicate that introduction of auditory stimulation enhances visual exploration in early infancy. Haith, Bergman, and Moore (1977) studied visual scanning of an adult's face by infants who were 3 to 11 weeks old. A dramatic increase in fixation of the face occurred between 5 and 7 weeks, and the introduction of a voice intensified scanning, particularly in the eye area (see also Hainline, 1978). Horowitz (1974) and her colleagues conducted a series of studies of habituation to visual displays with and without auditory accompaniment. Infants of 5 to 14 weeks habituated to a visual pattern accompanied by a continuous sound, such as a voice reading poetry, and subsequently dishabituated when the sound was changed. The change in sound led to further looking without a change in the visual display, as if the infant were searching for a change in the visual scene as well (see also Walker, 1982).

Exploration of the visible source of an ongoing sound has been observed with a preference method (Spelke, 1976). Motion picture films of two events were presented side by side on a small screen before the baby. During the filming for each event, a sound track was made. One of the two sound tracks was played from a central location as the baby viewed the films. An observer stationed behind the screen monitored the baby's looking so that the total looking time to each film could be assessed. Infants looked longer at the film specified by the sound track. A search test given after presentation of the films and both sound tracks provided further evidence for coordination (Spelke, 1979, 1981). The films were again presented side by side. On each of a series of trials, the baby's gaze was centered by means of a flashing light, a short burst of one sound track was given, and the baby's orientation to one film or the other was noted. Infants looked to the event specified by each sound. A number of experiments using this method have now been performed with 4-month-old infants (e.g., Bahrick, 1980; Bahrick, Walker, & Neisser, 1981; Spelke, 1976, 1979; Walker, 1982). These experiments have displayed a variety of events, including peekaboo, patacake, hands playing musical instruments, and bouncing puppets (see *Obtaining Information About Events*). Visual-auditory exploration of a temporally extended event is highly functional by 4 months.

Finally, there is some evidence that sound influences visual tracking of an object that moves laterally and is temporarily occluded (Bull, 1978, 1979).

A sound moving with the occluded object facilitated looking to the object's point of reappearance from behind the occluding screen at 4 months of age.

Haptic Exploration

Haptic exploration occurs earliest in the form of mouthing, whereas active manual exploration of objects appears considerably later. There is reason to think that mouthing activity of neonates is spatially oriented toward external events, as is activity of the visual system. Alegria and Noirot (1978, 1982) observed asymmetrical mouthing as a function of absence versus presence of a human voice and as a function of the voice's location. Asymmetrical mouthing came to be directed toward the voice within the first three feedings. Breast-fed babies (held either on the right or left arm for feeding) oriented toward the voice, whereas bottle-fed babies showed mouthing in the direction of the arm that characteristically held them. Asymmetrical mouthing was negligible in the control condition when the baby was held but not spoken to.

An experiment by Meltzoff and Borton (1979) provides evidence that mouthing is exploratory, that it furnishes information about the surface properties of objects, and that it is coordinated with looking at objects. Infants 4 weeks of age were allowed to explore by mouth one of two objects—a smooth sphere or a sphere with nubs. The objects (actually, larger versions of them) were then presented as a pair for visual inspection. The infants were reported to look preferentially at the object similar to the one familiarized by mouthing. Infants 4 months old, in a similar experiment, looked longer at the novel object (Meltzoff, 1981). The infants apparently learned something about the object from haptic exploration that was also detectable visually. However, a recent experiment with infants 1, 3, and 5 months old failed to replicate these effects (Baker, Brown, & Gottfried, 1982).

Oral exploration was used by Gibson and Walker (1982) in an experiment on intermodal perception of substance by 4-week-old infants. A cylinder-shaped object made of either lucite or spongy rubber was inserted in the baby's mouth and left until the baby had mouthed it for 60 sec. A test of preferential looking followed. Identical cylindrical objects were displayed simultaneously side by side before the infant, one object rotating in a pattern characteristic of a rigid substance and the other object deforming in a pattern characteristic of a spongy substance. The infants looked preferentially toward the object moving in the pattern of the *novel* substance. This experiment also provides evidence for detection of an intermodal correspondance.

Oral exploratory behavior was investigated directly by Allen (1982), who recorded pressure changes during oral exploration of objects. Infants of 3 months showed a decreased rate of sucking during familiarization with one object. They subsequently differentiated between the familiar object and a novel object of a different shape, sucking more vigorously on the novel object.

Infants learn very readily to suck at high amplitudes to obtain some contingent, seemingly arbitrarily related display, such as a human voice uttering "ba" or "ga" (e.g., Eimas, Siqueland, Jusczyk, & Vigorito, 1971). This learning may be facilitated by the exploratory function of mouthing, which is especially adapted for the pickup of information about affordances at an early age when other means of exploration are limited. An experiment by Kalnins and Bruner (1973) supports this interpretation. Infants 5 to 12 weeks old quickly learned to suck at high amplitudes when sucking brought a motion picture display into focus. But in the symmetrical condition, in which a picture came into focus only when the infant inhibited sucking, no learning occurred. Instrumental learning in infancy appears to build on the infant's inherent propensity to explore.

Mouthing continues as a means of exploration all through the first year of life. It is still used in preference to manual exploration between 8 and 9 months. Kopp (1974) studied visual-manipulative behavior of infants between 32 and 36 weeks of age when presented with a rigid object. Types of behavior included examining by turning an object in the hands and looking at it, mouthing, and actions like banging or sliding the object on the tabletop. Mouthing was the predominant behavior, followed by examining. Some infants still only explored the object visually.

Active touching and manipulation of an object with differentiated finger movements is late in developing. The precedence of the mouth over the hands for haptic exploration recalls Gesell's anatomical rule of head-downward and proximodistal development. But by 1 year children do explore the affordances of objects manually to some extent, differentiating elastic and rigid substances with such behaviors as squeezing versus banging (Gibson & Walker, 1982). Ruff (in preparation) reported an increase in exploratory fingering of objects between 6 and 12 months, particularly when the objects varied in surface texture.

Visual-Haptic Exploration

What is especially interesting about the haptic system is its tie-in with the visual system, which generally instigates haptic exploration. The hand-to-mouth coordination (look at an object, pick it up, and then mouth it) does not occur until about 6 months, but there are intimations of coordinated looking and reaching much earlier.

Research by Bower suggested that even a newborn infant will reach for a visible object under suitable conditions (see Bower, 1974, 1979, for reviews). Newborn infants were reported to extend an arm more toward a solid object than to a flat, extended surface depicting that object (Bower, 1972; Bower, Dunkeld, & Wishart, 1979), and more to an object within reaching distance than to one too far away (Bower, 1972). The newborn's arm extensions were reported to be adapted to the object's visible direction (Bower, 1974) and even its shape (Bower, 1972; Bower, Broughton, & Moore, 1970a). However, other investigators have failed to replicate these observations in studies with neonates (Ashmead, Lockman, & Bushnell, 1980; Dodwell, Muir, & DiFranco, 1976; Rader & Stern, 1981; Ruff & Halton, 1978). DiFranco, Muir, and Dodwell (1978) found many of the components of mature reaching in very young infants, but little evidence of the control characteristic of mature reaching. The arm extensions of neonates may be visually triggered without being as yet visually guided.

Two recent studies have more carefully examined the orientation of arm movements to visually presented targets in very young infants. McDonnell (1979) performed a signal detection analysis on the distribution of arm movements as a target changed position from center to the left or right side with infants from 3 to 8 weeks old. Results supported the view that infant limb movements are oriented to visual targets and that there is improvement in the accuracy of these movements from 3 to 8 weeks. Von Hofsten (1982) studied arm and hand movements in newborns presented with a slowly moving object. The relative frequency of forward extensions increased when the infant fixated the object. These extensions were analyzed by a technique that took into consideration the three-dimensional properties of arm-hand movements. The movements performed while the infant fixated the object were aimed closer than other extensor movements. They clustered round the object and the hand also slowed down, in the best aimed movements, as it neared the object. There does, thus, seem to be a primitive eye-arm coordination in the newborn that is adapted to the three-dimensional layout of objects well before grasping and active manipulation occur. This embryonic form of eye-hand coordination appears to have an orienting function. From the beginning, the infant focuses on events in the world.

Further experiments provide evidence of behavior precursory to reaching by 2 months of age. Bruner and Koslowski (1972) observed infants between 8 and 22 weeks and concluded that they were "able to make use of visual information in the regulation of early pre-reaching—information prior to that provided by feedback from early attempts at visually directed reaching" (p. 13). Infants who were not yet capable of a successful visually directed reach were, nevertheless, able to stretch their hands to midline in the presence of a small graspable object and did so more than in the presence of a larger, nongraspable object. A swiping motion, more akin to palpating than to grasping, was likely to be evoked by the larger object. Provine and Westerman (1979) observed infants' extension of one arm when the other arm was restrained. At 9 weeks, all infants tested reached for and touched an object presented in front of the shoulder of the freely moving arm, although they could not as yet cross the midline to touch an object in front of the opposite shoulder. At 18 to 20 weeks, all infants crossed the midline, opened the hand, and extended the fingers toward the object. Many infants succeeded in grasping it as well as touching it.

The development of reaching skill has been studied in detail in the past (see Gesell & Amatruda, 1964) and will not be examined here. But recent studies of reaching at an early age in relation to properties of an object or surface are of interest. The distance of the object from the infant, for example, may affect early prehensile behavior. J. Field (1976a) observed both the reaching and looking of 2- and 5-month-old infants in the presence of objects placed at several distances within and beyond possible reaching contact. Only the 5-month-old infants adjusted their reaching to the object's distance, but visual attention was affected by object distance in the younger group (see also McKenzie & Day, 1972). The 2-month-olds also showed differentiation in one category of arm adduction that appeared to reflect a distinction between reachable objects and objects far beyond reach.

In another study (J. Field, 1976b), infants from 13 to 25 weeks old were shown solid objects and pictures of objects placed at three distances. Pictures cut from paper were pasted upon the same board that was placed behind the objects. Both reaching and visual attention were observed. There was a significant effect of distance on the frequency of reaching toward the objects at every age level. From reaching alone, there was no evidence that infants discriminated between objects and their pictures until 24 weeks. There was little active manipulation before 24 weeks when most infants grasped the object and touched the wall or the picture. Even the youngest age group differentiated the object from its picture, however, as indicated by longer periods of looking at the object. Both a surface within reach (wall with pictures) and an object within reach apparently trigger visually elicited reaching and touching at these ages. Young infants do not fail to distinguish a flat surface from an object but show primitive tendencies to explore both.

Reaching for a moving object has been studied by von Hofsten (1979, 1980) and von Hofsten and Lindhagen (1979). Catching a moving object would appear to be far more difficult than grasping a stationary one, because extending the arm and opening the hand must be coordinated with the velocity and the trajectory of the approaching object. It is truly fascinating to discover, from these expert longitudinal studies, that infants reach successfully for moving objects as soon as they master reaching for stationary ones. The infants anticipate an object's future location after a time lapse, reaching and grasping to its anticipated position. Von Hofsten and Lindhagen (1979) seated the infants within reaching distance of a point in the trajectory of an attractive object mounted on a sort of boom that traveled at a velocity of 30 cm/sec. in a horizontal circular path. Infants 18 weeks old caught the object as it moved. Reaching skill improved during the period studied; the number of movement elements decreased with age and the first visually elicited step increased in speed and amplitude (von Hofsten, 1979). But reaching was predictive in the lowest age group; the hand was aimed at the point where it would meet the object rather than the point where the object was seen when the reach was initiated (von Hofsten, 1980). These results do not suggest a gradual integration or mapping of manual and visual schemata, with glances from hand to object, but rather a preadapted coordination.

Attention to tactually given information (manual, at least) is far from being as strong as attention to visually given information in the early months (Bower et al., 1970a; Gratch, 1972). Active, exploratory touching (squeezing, fingering, poking, and rotating) becomes skillful only as the infant becomes able to coordinate the use of both hands. The question here is, How early do visual and haptic exploration occur together, permitting discovery of intermodal invariants?

Hutt (1967) made an extensive study of a 7-month-old infant's manipulatory and visual exploration of novel objects. Manipulation began with a clutching pattern, often followed by half-turns of the wrist that resulted in different aspects of the object being viewed. Later in the month, the object began to be turned over and over while held in both hands. All these movements were accompanied by visual inspection and an intent facial expression.

Harris (1971) found that 8-month-old infants searched more for an object that they had examined both visually and manually than for one examined only visually, so touch would seem to be playing some role at that age. In another study Harris (1972) asked whether infants of 6 to 14½ months touched and looked at the same time; he concluded that visual and tactual inspection were synchronized. Older infants sought to touch an object that they had only inspected visually before, as if they wished to confirm its properties. Later studies are in some disagreement as to whether infants touch and look concordantly as early as 6 months (see Rubenstein 1974; Ruff, 1976; Schaffer, 1975; Schaffer, Greenwood, & Parry, 1972; and Schaffer & Parry, 1970).

Visually directed reaching, although well established, may not necessarily be followed by continued synchronous visual-tactual exploration when the haptic system is still rather poorly controlled, particularly when the object reached for lacks interesting or novel tactual-haptic properties. Steele and Pederson (1977) compared the effect of changes in shape, texture, and color of the objects to be inspected visually and manually by infants of 6 months. Looking and manipulation increased upon introduction of a novel object when shape or texture were changed, but only looking increased when color alone was changed. Concordance of visual-manual exploration was apparent only when new information common to both modalities was introduced. Exploration is, thus, appropriately selective even at this early age.

Other properties of objects that might induce visual inspection and also manipulation are not necessarily apparent until some manipulation has occurred, for example, substance and sound-making properties. An object's substance (e.g., hardness vs. plasticity) is observable visually when it is handled (via rigid vs. deforming motions), but not necessarily when it is stationary. An object's characteristic sounds (e.g., rattle noises) are often revealed only when it is manipulated. Properties such as plasticity and sound potential were found to be attractive ones for inducing manipulatory play and concordant visual regard by 8½ months, whereas sheer configural complexity was not found to be very effective (McCall, 1974).

In a study of the development of play between 7 and 20 months, Fenson, Kagan, Kearsley, and Zelazo (1976) recorded episodes of "simultaneous visual and tactual contact with a toy." Such episodes lasted an average of 8 min, even at 7 months of age. The nature of the play changed with age from mouthing and banging to activities involving several objects and a variety of actions. Even banging, however, provides information about an object's substance, weight, and sound potential.

Auditory-Haptic Exploration

We may conclude that a seen object elicits arm extension and primitive forms of exploration very early; so perhaps does an object that is specified by sound alone, although it loses this power later in infancy. Wishart, Bower, and Dunkeld (1978) studied auditory-manual coordination in sighted babies tested with a noise-making toy in the dark. They reported that the tendency to extend the arm toward a noise-making object was present in early months, peaked at about 5 months, and then declined. Bower (1979) felt that this decline indicated the beginning of "dissociation of the senses," which he assumed to be undifferentiated at birth. Actually, discontinuous sounds are poor sources of information for a layout with continuous surfaces that persist and support objects. Blind babies are notoriously late in reaching for noise-making objects (Adelson & Fraiberg, 1974), as are sighted babies tested under analogous conditions at around 9 to 10 months.

Search for an unseen sound-producing object was less successful than searching for a soundless object that was seen being hidden (Freedman, Fox-Kolenda, Margileth, & Miller, 1969). Bigelow (1980) found that search for a sounding object was not pursued once it was no longer seen until children had reached or passed Piaget's Stage 4 of development of object permanence. These findings were confirmed and extended by Uzgiris and Benson (1980) in several experiments on the use of sound in the search for objects by infants between 9½ and 11½ months. Sound was more effective in directing search in younger infants if the sounding object had been seen, manipulated, and made to sound before being hidden. Search was less successful when a previously unseen, untouched, and unheard toy was sounded in a hiding place, although the infants frequently oriented toward the sound.

In these experiments, children do not explore an object for knowledge of its properties but hunt for an object in the environment by using sound as a guide. It is hardly surprising that a young infant's skill in this enterprise is limited, since sound is the least rich source of information about objects and places for humans, and it is a poor guide to search at any age. Sounds do not direct exploration of objects at all in many cases, but when they do (crumpling paper, shaking things that rattle, banging things together), they are attended to with interest and provide information about the object's properties, especially about what the object affords.

The Development of Selectivity

Although the exploratory activities of infants are far from random, they appear to become increasingly specific and systematic with age. Exploratory skills develp along with the development of knowledge of what has utility for a task and of differentiation of relevant from irrelevant information (Gibson & Rader, 1979). This development is particularly evident when children attempt to perform tasks set for them by others, such as to compare two objects or scenes, to follow one event and ignore another, or to find an object in a cluttered scene.

Zinchenko, van Chzhi-Tsin, and Tarakanov (1977) presented preschool children with an irregularly shaped object for visual inspection. Visual fixations were recorded and a subsequent shape-matching task was administered. Children 6 years old tended to fixate all around the boundaries of the object and performed well on the matching task. Younger children were more apt to fixate the center of the object, where the lens of the eye-movement camera was located. Not surprisingly, the children who attended to the camera lens performed less well on the shape-matching task. These findings may reflect only age differences in comprehension of the task demands or in motivation to fulfill them. But, alternatively, they may reflect developmental changes in the ability to engage in systematic visual exploration for the purpose of some task.

As children grow, their haptic exploration of objects also develops. Zinchenko (cited in Zaporozhets, 1969) presented preschool children with the same irregularly shaped object to explore manually, and he followed this exploration with a haptic-matching task. By 6 to 7 years, children systematically traced the contours of the object with their fingers. Younger children tended to clutch the object in one place, with little exploration of its boundaries. The children who explored systematically performed better on the matching task. Haptic exploration, driven by the demands of a task, evidently improves over the preschool years.

In the above studies, children must explore an object as fully as possible to recognize an identical object on the matching task. Other studies have required children to discriminate between two objects. A discrimination task requires that the child explore the objects in search of the critical information that distinguishes them. Over the course of childhood, this search becomes increasingly economical.

Nodine and his colleagues (Nodine & Evans, 1969; Nodine & Lang, 1971; Nodine & Simmons, 1974; Nodine & Stuerle, 1973) investigated the eye movements of children in the early school years while they made same/different judgments of pairs of letters and letters presented in strings. Scanning became much more efficient with age. Scanning between critical target comparison areas increased, unnecessary scanning within letters or within a letter string declined, and the number of fixations decreased markedly. The oldest children (third graders) appeared to know what letter in a string and what aspects of that letter contained the critical information for discrimination, and they looked for that information directly.

The development of increasingly efficient, task-directed information pickup is evident in many experiments. An experiment by Lehman (1972) will serve as an illustration. She used a haptic comparison task to investigate school children's (K through sixth grade) information-gathering strategies. When the children were instructed to match two objects of the same shape or texture, with both dimensions varying, even kindergarten children restricted their manual exploration of the objects to the relevant property. But when the children were not told what feature was relevant and the two features were redundant so that only one needed to be explored for a correct choice, the older children learned to explore only one feature early in the task, whereas the younger children took longer either to discover the redundancy or to perceive its utility. When the redundancy was pointed out, selective exploration was enhanced at all ages.

Pick, Christy, and Frankel (1972) used a visual comparison task to study development of selectivity in second and sixth graders by means of wooden animals that varied in shape, color, and size. In one task, the children were told which aspect to compare before viewing a pair of the wooden animals. In another task, they were informed only after stimulus presentation. Reaction times were facilitated by prior instruction, especially for the older children. In another study, Pick and Frankel (1974) used the same sort of task, but the relevant feature for comparison was either predesignated for blocks of trials or else randomly designated from trial to trial. Random presentation was more disturbing to the younger children, leading the authors to conclude that older children are more flexible in their strategies of selective attention (see also Pick & Frankel, 1973; Pick, Frankel & Hess, 1975).

The degree to which one can generalize from any one experiment to another situation is always a problem. Flexibility of selection may develop rather specifically, depending on the task. An experiment by Condry, McMahon-Rideout, and Levy (1979) is in many ways comparable to the Pick et al. (1973, 1975) experiments, but the materials and the judgments were different. Second- and fifth-grade children as well as adults made similarity judgments on sets of three words projected on a screen before them with respect to graphic, phonetic, or semantic information. The words were arranged in a triangular display, with the upper word as standard and the two lower ones for comparison. The subject might be given a set of words, with one pair close in meaning, and asked to choose the word that looked, sounded, or meant most nearly the same as the standard. For half the subjects, the judgments were arranged in blocks, with all the trials in a block requiring a match on just one of the three properties. The other subjects were presented with sequences in a random arrangement, and the required comparison was designated just before the trial began. All the subjects were facilitated by the blocked arrangement; there was no interaction of blocking with age, as Pick and Frankel (1973) had found. Overall improvement in performance increased with age (reaction times decreased) and irrelevant information had a less detrimental effect, but flexibility in shifting attention without blocking did not increase.

An aspect of selectivity that has often been shown to develop with age is a trend toward more efficient use of specific features of information presented. Perception in tasks that are repeated becomes progressively more economical through detection of only those features of available information that have greatest utility for performing the behavior required. Detection of the affordance of the minimal criterial information has been demonstrated repeatedly (see E. J. Gibson, 1969, pp. 462 ff.; Gibson & Levin, 1975, pp. 43 ff.). When critical features for guidance of performance are defined redundantly, the most economical information tends to be selected. Pick and Unze (1979) had preschool and older children select a set of three designated letters from a box containing a collection of letters. As redundancy was introduced (e.g., coloring the designated letters differently from the rest of the assortment), children of all ages profited, especially the older ones. The youngest group profited even more when the redundancy was pointed out. Seeing the affordances and making economical use of them begins early and increases developmentally.

In the above tasks, children were presented with either a single object or a pair of objects for exploration and comparison. In other tasks, children have been presented with an displays of objects to explore. With age, exploration of such arrays becomes increasingly systematic and efficient as well.

A number of developmental studies of exploring and comparing two displays were performed by Vurpillot (for summaries, see Vurpillot, 1972/1976, chap. 9; Vurpillot & Ball, 1979). The task was to judge whether pairs of line drawings of houses were the same or not. Each house in a pair contained six windows that were arranged in two vertical columns of three. Within each window were pictures varying details (plants, curtains, laundry on a line, etc.). A pair of houses could be identical with all the sets of six windows matching or they might vary in one or a number of details in one or more pairs of windows.

Children's scan paths (eye movements of comparison) became increasingly economical between 4 and 9 years. The proportion of comparison movements between houses increased, as did the proportion of these movements that were horizontal (most informative). The most efficient strategy was homologous comparison: an eye movement that went directly from window *a* in one house to window *a*, its homologue, in the other. The number of subjects making such comparisons were 0 out of 18 in the youngest group and 18 out of 20 in the oldest group. Above age 6, nearly all the children made some homologous comparisons. Vurpillot & Ball (1979) consistently found that the preschool children based their judgments on only a limited amount of the available information, whereas older children used any potential difference between the stimuli in making their judgments.

Vurpillot and Ball (1979) suggested that the development of search reflected a change in how children understood the comparison task. Young children may have thought that two houses should be judged the same if they were equivalent in their overall structure; older children may have thought that the two houses should be judged identical only if they were identical in all their contents and in the arrangements of those contents. It seems possible, however, that children also developed new and more systematic strategies of search.

Experiments on search behavior by Russian psychologists support the latter interpretation (see Venger, 1977). Children of 3 to 7 years were observed while searching for a designated target (a strip of given magnitude or a color chip) in a series of strips varying in magnitude or in a color array classified according to hue, brightness, and saturation. In some cases, the items of the array were arranged systematically; in some they were randomized. In searching for a strip of designated length, the youngest children seldom referred back to the model and failed to examine many elements of the array, even when the array was arranged systematically. Search time increased in a middle group, with more looks at the model and more elements examined. In the oldest group, search time decreased and proceeded systematically. The youngest children scanned a random series in much the same way as an ordered one. The older children took account of the series properties and scanned a "bracketed" area in an economical fashion in the ordered arrays. Some of them appeared to use the series properties even when the series was randomized.

When colors were presented in an ordered array, age differences were especially apparent. The youngest children searched nearly as chaotically as with a random array. The older children divided the process of searching into two stages, as disclosed by their eye movements. The first stage consisted of vertical and diagonal sweeps, followed by horizontal movements increasing regularly in fixation time until the match was selected. They were using the properties of the color system, searching first for the required hue and then scanning horizontally within a graduated series of shades lying within the chosen hue. Search strategies based on affordances and order in the array are developing during the early school years, yielding even more economical search behavior.

Finally, a few studies have investigated children's exploration of a three-dimensional layout in search of an object. These studies, too, reveal that search becomes more efficient and systematic.

Drozdal and Flavell (1975) presented children of 5 to 10 years with a model house consisting of 14 connecting rooms and two dolls representing a boy (Charlie Brown) and a frog. As these objects were placed in the first room, a story was told in which Charlie and the frog were said to move through the house. The children could not see the movements of the dolls because the walls of the house were opaque, but the story was illustrated with cartoon drawings. As Charlie entered the fifth room, the frog was said to be present; by the seventh room, it was discovered to be lost. Charlie Brown continued through the house alone. Children were asked, at the end of the story, where they should look for the frog. They were probed to determine whether they realized that the frog had to be within a critical search area, in rooms 5, 6, or 7. Children 10 years old uniformly appreciated this fact; children 5 years old did not. Drozdal and Flavell concluded that this aspect of logical search behavior develops in middle childhood.

Because Drozdal and Flavell's (1975) study involved a model environment that the child never encountered directly, developmental changes in logical search may partly reflect the older child's greater ability to imagine unseen paths through an unseen environment. Studies by Wellman, Somerville, and Haake (1979) provide evidence for logical search at younger ages in a study in which an object was lost in a playground. The logic of the study was similar to that of Drozdal and Flavell (1975). A child of 3 to 5 was taken by an experimenter through a playground divided into eight areas. In the third area, the experimenter took the child's picture. In the seventh area, the camera was discovered to be missing. The child completed the path through the eighth area and then was asked to search for the camera. Children of all ages tended to search first in the third area, where the picture had been taken. Most of the 3-year-olds did not search at a second location; those who did tended to search outside the critical area, in the first or second locations. Older children were more likely to confine their second searches to the critical area. These findings indicate that the tendency to search comprehensively within a critical area develops over the preschool and early school years.

The study by Wellman et al. (1979) indicated that preschool children have some capacity to search logically for an object if it is lost in a natural setting that the child has walked through. But even this study may underestimate young children's abilities because the children were led through the playground by the experimenter. A child may locate objects in a large setting even more effectively if she has been allowed to explore that setting actively. Feldman and Acredolo (1979) introduced 3- to 4-year-olds and 9- to 10-year-olds to a network of corridors within which they found a cup. Half the children searched for the cup on their own, the experimenter following behind. The others looked for the cup as they were led through the corridor by the experimenter. All children were subsequently asked to find the place where the cup had been. The older children were more accurate in their estimates of the cup's location, but at both ages, the children were more accurate if they had explored the corridor actively. By exploring, children evidently pick up more information about an environmental layout.

Following an event is always selective because, at any given time, multiple changes are taking place in the flux of stimulation. Selective exploration of events becomes especially remarkable when the attended event is accompanied by other, potentially confusable happenings that could distract the child. Do children become better able to resist such distraction as they grow and to follow one event exclusively?

This question has been addressed through studies of selective listening. In such studies, the child is instructed to attend to and report about one of two tape-recorded verbal messages. The earliest research with children was performed by Maccoby and her colleagues (1967). Each of two very short messages was presented to different ears or in voices of different sex. Children as young as 5 years could attend to one voice selectively, although the number of intrusions from the unattended message declined with age. Related experiments by Anooshian and McCulloch (1979), Anooshian and Prilop (1980), Clifton and Bogartz (1968), and Doyle (1973) have generally found some developmental improvement, but the measure has typically been retention rather than detection of appropriate information.

Experiments by Geffen and Sexton (1978) and Sexton and Geffen (1979) used detection tasks more pertinent to perceptual selectivity. The subjects (children from 7 to 11 years and adults) were to listen to pairs of words presented simultaneously and press a key if the target word was heard. The words were played to different ears or spoken by different voices. When 7-year-olds were instructed simply to attend to one ear exclusively, their hit rate

was as good as in a control condition with no competing voice. Hit rate increased with age in general and number of intrusions decreased. Age effects were most notable as instructions became more difficult to follow (e.g., "attend to one ear, but press the key if you hear the target word in the other"). The ability to divide attention (listen to both ears equally) did not change with age. Thus, older children appear better able to follow complicated instructions in a flexible manner.

It is interesting that even the youngest children can attend to one message selectively in simple detection tasks. Can infants attend to a voice selectively as well? Benson (1978) investigated this ability in infants of 12 and 25 weeks, both with and without spatial separation of background noise and signal. The background noise consisted of a babble of voices (four men's and four women's voices reading aloud). It was played continually from a loudspeaker directly in front of the infant. At specified intervals, a new voice was added from a loudspeaker either in front of the infant or 90° to the side. This signal was either the mother's voice greeting the infant or a control signal consisting of a segment of the babble. Heart rate was monitored continuously. There was a significant deceleration of heart rate when the mother's voice was added, but not when babble was played. Detection was facilitated when the mother's voice was separated from the babble, but there was a small, reliable deceleration even without any spatial separation. The older infants showed a larger deceleration, but there was significant detection of the mother's voice at 12 weeks. More infants smiled, also, after hearing the mother's voice than after exposure to the added babble. Figure and ground, under these conditions at least, are separated. Even young infants do not hear simply a "blooming, buzzing confusion" and can attend to a meaningful event despite competing contextual information.

The mother's voice is an event of special significance to the child, and it might be attended selectively for that reason. But a final study (Bahrick et al., 1981) indicates that 4-month-old infants can attend selectively to other events as well. This experiment used a visual analogue of a selective listening task, in which two visible events are presented so that they overlap each other on a screen and the subject is asked to follow one of them (Neisser & Becklen, 1975). In the present case, filmed events of four hands playing a clapping game and of two hands operating a slinky toy were superimposed. Infants could not, of course, be asked to follow one of them, so a variant of Spelke's (1976) auditory-visual preference method was used. The two movies were projected one on top of the other and the sound track to one movie was played. The infants were apparently able to segregate the events and to follow the event accompanied by sound. After familiarization with this display, projection of the two films silently and without superposition indicated that the infants had habituated to the one accompanied by sound and now looked at the other one. It appears, therefore, that perception is selective from the start, at least when the infant is given the opportunity to follow an event.

Overview

Exploring the environment is the key to detecting information about it, and the human neonate is well provided with coordinated systems for exploring. These systems, moreover, are coordinated with each other to foster perception of a unitary world by looking, listening, and touching. Nevertheless, some perceptual systems are more mature at birth than others (the visual vs. haptic systems for example), and each system will undergo enormous changes with development. Children will come to explore objects, events, and places more efficiently and flexibly.

As children progress to the performance of instructed tasks, they must learn to explore and search for relevant information economically. They become better able to do this as they come to understand a task better, as perception becomes more differentiated, and as their exploration becomes more flexible. But exploration is active, selective, and systematic from the start, as infants investigate objects and events spontaneously for the purpose of discovering their affordances.

OBTAINING INFORMATION ABOUT EVENTS

The active perceptual systems of the young infant provide stimulation that is continuously changing. In this flux of stimulation, there is information both about changes in the surface layout and about the stable characteristics of the layout. Through changing arrays of stimulation, perceivers obtain information about events. These events, in turn, provide information about objects, surfaces, and their persisting properties, since invariant relationships are preserved over change. This section focuses on the perception of events and their properties. In later sections, we will discuss the role of events in specifying constant properties of objects and places.

Two Views of Event Perception

Our focus on events is hardly traditional. In the early history of experimental psychology, research on perception was confined largely to static phenomena, for example, color, illusions, and depth observed under purely static conditions. The reasons for this choice may have had to do with limitations of equipment and probably, too, with the then current theoretical background of British empiricism. Most early psychologists believed that perception depended on elementary sensations joined together by association. Perception of movement was thought to be derived from the integration of static impressions.[1] This view penetrated to developmental psychology: It led to research on "the problem of temporal integration" and to the hypothesis that integration was improved or speeded up developmentally (e.g., see Schnall, 1968). Research on this problem has customarily presented subjects with separate piecemeal glimpses of a display presented sequentially, thus, forcing integration (Girgus, 1973; Girgus & Hochberg, 1970). It is interesting that, even under these impoverished conditions, young children can sometimes perceive objects and events. A succession of static displays, if presented with appropriate rapidity, leads to perception of an event with change over space and time. Perceiving such an event, for example, stroboscopic motion, does not depend on associative learning, because it is perceived by neonates (Tauber & Koffler, 1966).

We will be concerned here with the perception of events in which information is flowing naturally over time rather than with a succession of frozen displays, for we conceive of perception as primarily and primitively the pickup of information within a continuous spatiotemporal flow (J. J. Gibson, 1950, 1966, 1979). By this view, events are the principal aspects of the world that require and receive the attention of an animal. They supply structured information for the perceptual systems; and they are perceived as unitary, bounded, meaningful happenings. The development of event perception occurs through a process of differentiation rather than integration, and this differentiation begins early in life. Event perception is not a late achievement that results from an integration of static pictures but a fundamental ability that underlies the perception of the constant properties of the world.

What Is an Event?

Events have been variously defined. To J. J. Gibson, events are of three kinds: "Change in the layout of surfaces, change in the color and texture of surfaces, or change in the existence of surfaces" (1979, p. 94). To Johansson, an event is "a generic concept denoting various kinds of relational change over time in a structure" (1978, p. 677). Both definitions imply that an event involves both transformation and invariance—both a changing and an unchanging structure. These changes and invariances can be considered distally (as physical changes in a stable layout), proximally (as patterns of change and invariance in the information available to pickup systems), and perceptually (as the registration of change and constancy by an organism). However defined, an event involves a change over time and an invariant property that persists. Invariants of events are abstract and usually amodal, for example, a rhythm. Rhythmic patterns can be presented acoustically, optically, or on the skin and still keep their identity as a pattern. Invariants confer unity on events—an event has a beginning and an end and many events have points of articulation or centers of underlying structure. Invariants also specify the properties of events and their affordances.

Johansson's studies of motion perception provide one particularly interesting example of how the unity of an event is specified by abstract invariant information. Johansson filmed motion patterns representing the activity of locomotion in man without any concomitant pictorial information. This was achieved by means of a moving-dot technique (see Johansson, 1978). Ten small luminous points were attached to the main limb joints of an actor who was filmed in near darkness while walking, running, or dancing. Nothing was recorded on the film but a group of 10 bright dots, each moving in its own path. What is perceived is not a swarm of dots, but a moving person. Schoolchildren shown the films for as little as 200 msec reported seeing a walking man. They perceived the man as persisting over changes in his posture and location. The information for this invariance is entirely relational, abstract, and changing, and it specifies an event with coherence, structure, and meaning. Johansson describes this information in terms of vector addition—although the dots move in different directions, they share a common component direction. Detection of this common component leads to perception of the unity and persistence of the person, whereas detection of the remaining components of motion leads to perception of changes in the person's posture.

In Johansson's studies, the movements of dots must be perceived relative to each other for any coherent whole to be defined. Must an infant learn to perceive relative motion rather than unrelated absolute motions? Existing evidence indicates not. Lasky and Gogel (1978) in an experiment with patterns of three moving dots showed that infants of 5 months perceived their motions relative to each other. As we will see later, such relative motions provide information about the unity of an object for infants as well as for adults.

Another important characteristic of events is their hierarchical structure: Small events are embedded within larger events and may be differentiated into even smaller events. This hierarchical structure is particularly obvious in acoustic events such as speech and music. Segmentation of speech and music involves differentiation and analysis at many levels. In listening to speech, we segment the acoustic stream into sentences, phrases, words, and syllables. In listening to music, segmentation occurs at many levels also. Preschool children, before learning to read, may have difficulty breaking the speech stream into event units that are not determined by meaning (see Gibson & Levin, 1975, pp. 119 ff.). In the case of music, untutored listeners are less able to relate smaller events to superordinate themes (Frances, 1958). Perception of a high degree of embeddedness thus may come late in development. But some degree of embeddedness is perceived quite early, especially when the larger event contains repetitive subunits, like a game of peekaboo. Greenfield (1972) found that a 4-month-old infant quickly learned the structure of the game and anticipated the key feature of the subevent (reappearance after disappearance) even after specific vocal cuing was dropped.

Events have affordances. Speech affords communication with another, games afford socializing. These affordances are perceived with such immediacy that it is difficult to describe an event otherwise. Speech in one's native language cannot ordinarily be perceived as a jumble of meaningless sounds, try as one might. And even inanimate events with distinctive sounds like branches of a tree crackling in the wind, and man-made ones, like uncorking a bottle of champagne, are identified as meaningful readily and accurately by adults and even quite well by preschool children (VanDerveer, 1979).

Finally, events are not only given by the world around us. They are also created by the observer. Information about many things in the world, including the self, is only available by active participation in an event. A good example is touch. Touch must be active to get information about substance, texture, shape, and weight of objects. Touching is usually combined with active fingering, pressing, squeezing, poking, rubbing, and other activities. Even when some information is available without activity, an observer is likely to enhance his opportunities by adjustments that optimize exploration. As discussed earlier, some of these exploratory activities are present at the beginning of life.

Following Events by Young Infants

Events provide information about the world from the start of life. We have already noted, in the discussion on preadapted coordination, that neonates can follow an object moving in translation across the field of view. The fact that very young infants attend to and follow events is strong evidence against an integration view of event perception. Babies do not seem to perceive a series of frozen images, for they attend to moving objects consistently. For example, infants of 2 months look longer to moving objects than to stationary objects (Ames & Silfen, 1965; Carpenter, 1974; Cohen, 1969; McKenzie & Day, 1976; Wilcox & Clayton, 1968). Infants of 1- to 3-months also look to objects in the periphery more quickly if they are moving than if they are stationary (Milewski & Genovese, 1980). Finally, when an object is presented away from the infant's fixation point, the infant will turn to look at it over a greater range of distances, both laterally (Tronick, 1972) and in depth (McKenzie & Day, 1976), if it is moving.

What happens when infants are presented with motions more complicated than simple translation, where there is a change in the path of motion or an object's trajectory? Mundy-Castle and Anglin (1969) presented infants with a two-window display in which a decorative ball moved up in one window and then down in the other after a brief interval of occlusion. Infants under 1 month tended to fixate one window or the other, with few cross-looks. But by 30 days, there was an increase in the number of anticipatory cross-looks toward the opposite window after the disappearance of a fixated ball. Around 14 weeks, many infants followed an assumed trajectory over the top of the box containing the windows, during the ball's occlusion. So by 1 month, looking behavior began to be coordinated with the pattern of events. This experiment was repeated by Mundy-Castle (reported in Dasen, Inhelder, Lavallée, & Retschitzki, 1978) with Nigerian infants with similar results. Beginning at 25 to 70 days, they anticipated the appearance of the ball in the second window.

In real-life events, as in Mundy-Castle's experiments (1969, 1978), objects are frequently occluded either by other objects that pass in front of them or by objects that they pass behind. As adults, we do not perceive the occluded object as vanishing into thin air. We perceive, instead, an event in which one thing goes behind something else. There is no reason to suppose this perception is the result of an integration of frozen snapshots with the mind supplying an inference about the object, because there is information at the occluding edge for something going behind. The progressive deletion of structure of a target object as it is occluded (Gibson, Kaplan, Reynolds, & Wheeler, 1969; G. A. Kaplan, 1969) provides information for the continued presence of the object despite change. In an experiment by Yonas (1982), translation of a surface between a viewer and a second surface was specified by accretion and deletion of texture elements. For adults, these displays specify the interposition of one surface moving in front of another. Infants 7 months old reached more frequently to the virtually closer surface, whereas they did not with static presentation of the dot patterns.

There have been a number of experiments studying the effects of temporary occlusion of an object upon infants' perception of the object's continued presence and their apparent expectation that the object will reappear. The experiments have been motivated, for the most part, by an interest in the development of object permanence, knowledge of the identity and continued existence of an object when it is out of sight. In that light, results of the experiments are as yet ambiguous; it is not clear whether young infants conceive of an object as permanent (see Harris , vol. II, chap. 9). Nevertheless, these experiments are of interest for event perception.

The first of these experiments was performed by Bower (1967a). Two contrasting events involving disappearance were compared: one involved temporary occlusion of an object by a moving screen via a progressive deletion and then accretion of structure at the edges of the screen; the other event provided information for going out of existence by a sudden implosion. Infants between 49 and 55 days of age were observed with an operant procedure. The infants treated progressive occlusion as they would a nondisappearance, but reacted quite differently to the implosive disappearance. When spontaneous sucking was used as a response indicator, suppression of sucking provided evidence that a progressively occluded object was perceived as persisting.

Most subsequent experiments have focused on perception of the temporary occlusion of an object as it passed behind a screen, by observing the infants' anticipatory eye movements at the time appropriate for the object's emergence. If infants perceived the trajectory of a moving object as a unitary event, they would presumably follow the trajectory as if they were tracking a visible object. There is evidence that infants as young as 8 weeks do this, turning their eyes to the exit side of the screen and reaching it before or as the moving object emerges (Bower, Broughton & Moore, 1971a). In another experiment, Nelson (1971) reported that anticipatory looking did not occur the first time the object disappeared and that it occurred with only gradually increasing frequency on successive trials. However, Nelson's occluder (a tunnel through which a toy train engine passed) was 27-in. long (more than five times as long as that in Bower et al., 1971). Furthermore, the duration of occlusion changed randomly from one revolution to the next; only one of the durations was commensurate with the velocity of the engine. Infants may have failed to anticipate the emergence of the train because the duration of disappearance was too great or because the occlusion time was not commensurate with the observed velocity.

There are many parameters of these experiments that can be varied; for example, the duration of occlusion, the width of the occluder, the speed of the object's travel, the path of the trajectory, the attractiveness of the target object, and the response selected for observation. Unfortunately, all of these factors may affect the results, making apparent contradictions almost inevitable. However, some of the variations are of interest developmentally and theoretically. In one of the experiments of Bower et al. (1971a), conditions of the movement that specified the original trajectory were disrupted (inappropriate speed at emergence or too long a period of occlusion before reemergence). If an infant were really extracting an invariant trajectory specified by the beginning of the event, these conflicting conditions should produce disruptions of behavior. In fact, an "impossible" final trajectory (accelerated movement at emergence) resulted in no systematic anticipations, although a possible one regularly did. Nelson's (1971) experiment as well as an experiment by Moore, Borton, and Darby (1978) are consistent with this finding. The evidence, thus, confirms that quite young infants perceive invariant information for an event, specification of a trajectory over a transformation involving temporary occlusion. This result is by no means trivial because the information during occlusion is amodal and abstract (see, in particular, the discussion of the "rabbit-hole phenomenon" in Michotte, Thinès, & Crabbé, 1964). The result also complements nicely von Hofsten's (1980) finding that infants predict the trajectory of a moving object.

Picking up information for an event does not, however, guarantee that the event is fully differentiated. Does an infant also perceive featural details of an object that is being moved? In one experiment, Bower et al. (1971a) substituted one moving object for another during occlusion so that an object of a different color and shape emerged, moving along the correct trajectory. Up to 20 weeks, infants did not react to the change, but after that time they suppressed tracking and glanced back. There is conflicting information for the event in this case, which is resolved by young infants in favor of the invariant trajectory information rather than the object's static properties. This experiment was repeated by Goldberg (1976), who recorded heart rate as well as tracking. If infants were surprised by a change in features of the object, their heart rate was expected to decelerate. No evidence of such change was found in infants 20 to 24 weeks old. Neither was there change in visual fixation with a change in the object during occlusion, as Bower et al. (1971a) had found. Various conditions of the experiment (e.g., longer occlusion time) differed from the Bower et al. experiments, however.

A developmental comparison of perception of an object's motion trajectory, differentiation of its features, and permanence was conducted by Moore et al. (1978) with 5- and 9-month-old infants. The experiment presented three conditions designed to violate an infant's presumed expectations if she had knowledge of each of the three types. To violate expectations about an object's trajectory, an object reappeared from behind a screen faster than its original trajectory would have specified. To violate expectations about an object's features, the object disappeared behind a screen and a featurally different object appeared from the other side on the initial trajectory. To violate expectations about an object's continuous displacement, an object disappeared behind the first of two separated screens, but failed to appear in the space between them before emerging on the correct trajectory. The behavior observed was any indication of disrupted tracking (looking back, looking away, monitoring screen edges). Each condition had an appropriate control. Infants 5 months old quite consistently showed disrupted tracking behavior when the trajectory and the feature conditions were violated. The 9-month-old infants displayed evidence of disrupted tracking in all three conditions, including the continuity condition. The younger infants evidently expected the object to move smoothly without changing its color or shape, and the older infants also expected it to move continuously over space and through time.

Two further experiments have investigated the effect of changing the moving object while it is occluded. Muller and Aslin (1978) observed tracking of infants at 2, 4, and 6 months, with the shape or the color of a moving target changed during occlusion. Infants at all three ages showed smooth tracking as the object passed behind the screen and emerged, with no disruption because of changes in the object. Infants were capable of disrupting their tracking, however, and they did so if the object stopped short of going behind the occluder. When occlusion duration was varied, a longer occlusion led to some disruption of tracking, but there was no interaction with change in the object, even at 6 months. Muller and Aslin concluded that disruption of tracking was a poor measure for investigating the object concept or object identity because of spontaneous or chance disruptions of tracking.

Von Hofsten and Lindhagen (in press) performed the change-of-object experiment with 19-week-old infants using a measure of cardiac deceleration, as Goldberg (1976) had done, but with a much briefer duration of occlusion (less than 1 sec. as compared with 4 sec.). A habituation procedure, followed by a test for dishabituation, was used. When the object was changed behind the screen, deceleration occurred, but not when it was only occluded. Tracking data did not show disruption when the object was changed behind the occluding screen. Looking at these results as a whole, it does not seem possible to conclude anything about object permanence, except that numerous variables may affect the results; but the evidence does seem conclusive and plentiful that quite young infants perceive invariant information specifying the trajectory of an object over occlusion.

What do infants perceive when an event involves motion toward or away from the observer? Motion away from the observer is akin to information for disappearance, if the recession continues long enough. It indicates that something is moving out of the immediate surroundings. Progressive minification of the image of the object projected to the eye specifies the event. This is exactly what happens in nature when imprinting is observed in precocial animals. The mother moves away on a vanishing course; the precocial duckling or chick begins to run. It is interesting that artificial production of information for vanishing by means of a contracting pattern with a shadow caster is effective for inducing imprinting in chicks in the absence of featural information about a target object (Tronick, 1967). Safe following (without losing a target or colliding with it) follows the rule, stabilize the expansion pattern at the eye (J. J. Gibson, 1979). Adult drivers do this on highways, as do precocial animals in following the herd. Motion toward the observer provides information for imminent collision, and it is specified by a symmetrical, accelerated expansion pattern. The event is typically referred to as looming. Responses to looming with both simulated (shadow-caster) events and events involving real objects have been studied in infants. (For a detailed discussion, see *Perceiving Affordances of the Layout*.)

Events are specified acoustically as well as visually, and there is evidence that some of these are followed at an early age. It was noted earlier that neonates respond to certain kinds of acoustic stimulation, especially continuous sounds, by turning the eyes and head toward the sound source. They may also follow the event and differentiate its properties. For example, 2-month-old infants have been shown to discriminate simple repetitive rhythmic sequences (Demany, McKenzie, & Vurpillot, 1977). Perception of temporal grouping in auditory patterns has been studied with 5-month-old infants by Chang and Trehub (1977b). Following habituation of a cardiac response to a six-tone sequence with 2, 4 grouping, infants were given the same tonal sequence with 4, 2 grouping, with ensuing dishabituation. A sequence of eight notes arranged in ascending order was presented 4, 8, or 12 times for familiarization to 5½-month-old infants by McCall and Melson (1970). The same notes were then presented in a rearranged sequence. Cardiac deceleration to the rearranged sequence occurred, increasing as the number of familiarization trials increased (replicated by Melson & McCall, 1970).

Although infants in these experiments must have obtained some event information of a relational sort, it is not clear that the sequence of eight tones was heard as a whole. An experiment by Chang and Trehub (1977a) presented infants 4½ to 6 months old with a six-tone pattern of notes over 15 habituation trials. The response indicator was cardiac deceleration. Transpositions of the habituated pattern (three higher and three lower) as well as a pattern of the same notes in scrambled order were presented for dishabituation. Response recovery was not evident when the shift was to a transposed pattern, but it was evident when the shift was to a scrambled pattern. In the absence of a no-change control group, a conclusion is dubious, but the infants may have detected relational information in the tonal patterns—a property of the melody that was invariant over changes in its absolute frequency.

The events so far considered were specified by either optical or acoustical information alone. Events in the real world, however, are normally multimodally specified. We watch them, hear them, and often get kinesthetic and vestibular information about them. As adults, we perceive these events as units—unique happenings with one meaning. It may be that the best information for unity of an event is given in invariant information that is specified in many modes, for example, both optically and acoustically or both optically and haptically. Dynamic event properties, like tempo and rhythm, would provide event structure specifiable as the same in many modes. Adults are aware of such properties, for example, in watching and listening to a ballet or when dancing themselves. Preadapted coordinated systems for pickup of information are ideally suited to extract information for these abstract, amodal invariants. Is multimodally specified invariant information detected by infants?

Earlier research on so-called intersensory patterning with subjects from the early grades (Abravanel, 1968; Birch & Lefford, 1967) sometimes gave the impression that perceptual systems become increasingly integrated with age. The tasks that were used required matching of patterns across visual, auditory, or tactile presentations. But research with suitable intrasensory comparisons (Milner & Bryant, 1970) has made the integration interpretation dubious, and an experiment on intermodal perception of temporal sequences in infancy (Allen, Walker, Symonds, & Marcell, 1977) has stripped it of plausibility. Allen et al. presented infants of about 6 months with audible and visible sequences of three elements in two temporal patterns. An habituation procedure with one pattern was followed by a test for recovery with a new pattern or the same pattern as a control. There were

four groups, varying in mode of presentation of the two tests: auditory-auditory, visual-visual, auditory-visual, and visual-auditory. Heart rate and skin potential were the response indicators. Infants generalized habituation to the same pattern presented in a new mode, and all the infants dishabituated to a new pattern. Infants in the intersensory presentation conditions showed greater recovery to new patterns than did infants in the intrasensory conditions.

The events studied in these experiments were extremely simple and of short duration. As noted earlier, there is now evidence that infants follow more complex natural events specified optically and acoustically and attend to the bimodally specified information. Four-month-old infants look and listen preferentially to events such as a woman playing peekaboo and a hand beating a rhythm on simple percussion instruments (Spelke, 1976). Infants of 4½ months also look preferentially to sound-specified events that are less familiar: slinky toy and a hand-clap game (Bahrick et al., 1981). There was no common spatial information in these studies; the infants responded to internal temporal structure invariant over the two modalities.

Further experiments have investigated the information for unity in such bimodally specified events (see Spelke, in press, for a review). In one series of studies (Spelke, 1979), films were prepared using unfamiliar objects (toy stuffed animals) and sounds (thumps and gongs presented in sequences of locomotion and bouncing produced via puppet strings) accompanied by a sound track bearing some aspect of temporal invariance with the depicted locomotion in any given film. Each object made a different percussion sound. A pair of films with different objects and temporal sequences was displayed while one sound track located in a central position was played. The quality of the sound, being artificially produced, bore no intrinsic relation to either object. Infants could respond to the auditory-visual relationship only by detecting a temporal invariant. Three experiments tested whether infants could perceive a unitary event by detecting the synchrony or the common tempo of sounds and impacts. In Experiment 1, a sound occurred whenever the appropriate object landed on the ground, and the sound and impacts occurred at a distinctive tempo. In Experiment 2, each sound occurred in the same tempo as one of the objects, but it was not simultaneous with the impacts of either object. In Experiment 3, sounds were simultaneous with the impacts of one object, but their tempo was common to both the events portrayed so that only synchrony of burst and impact provided temporal invariance for uniting one film with the sound track. Infants detected the temporal relationships in all three experiments. Infants at 4 months of age do appear to be able to perceive unitary audible and visible events either by detecting the synchrony or the common tempo of sounds and impacts. Further studies indicated that infants can perceive a unitary event by detecting temporal relationships between sounds and other visible movements of an object—movements not culminating in an impact (Spelke, Born, & Chu, in press).

Other aspects of event structure could also provide information for bimodal unity. Microstructure within the event specifying properties of a substance (e.g., hard vs. spongy) may carry optical and acoustic information for unity (see Bahrick, 1980, which will be described in *Obtaining Information About Objects*). It is possible, also, that simultaneous information about the affordance or meaning of an event may be picked up visually and aurally to unite the event sequence. The affordance of an event, such as scissors converging on a piece of paper and cutting it in two, is easily perceived visually, and it is also perceived and identified correctly by an adult when only the sound, played over a tape recorder, is available (VanDerveer, 1979). When bimodal information is available, both the temporal structure and the affordance of the event might specify its unity to an infant. Could the affordance alone?

The question was explored by Walker (1982) in experiments on perception of expressive behavior in infants. Expressive behavior of adults, as revealed in changes in facial structure and accompanying vocalizations, provides information about the kind of interaction that can be expected, for example, pleasant, comforting, playful versus harsh, inattentive, somber. Walker prepared films of a woman displaying expressive behaviors judged as happy, neutral, or sad. She projected two films side by side and played the sound track for only one of them in a central location. Infants of both 7 and 5 months consistently looked longer to a filmed event when its appropriate sound track was played. Synchrony of temporal patterns could well have been responsible for perception of unity by the infants. But when the sound track was played out of phase with the event, so as to destroy synchrony, the infants were at first upset and looked back and forth at length, then settled down after 60 sec. or so to watching the film appropriate to the sound track. It seems plausible that they detected the common affordance of vocal and facial expressions and thus perceived a unitary event.

Differentiating the Properties of Events

Reversibility

One useful way of classifying events is on the basis of reversibility or nonreversibility. A reversible event is one for which there exists a transformation that can be applied to the final state to produce the initial state. Changes of location of an object in the surface layout are generally of this kind. As a man walks into the distance toward his mailbox, stimulation projected to the eye changes continuously, rendering the image smaller and smaller. But he peers in his mailbox and retraces his route, returning to his original position. Motion toward and away from an observer provides information for a persisting property of a movable object—its size. Such an event is very frequent in the world, even in the world of an infant, who sees his caretaker moving toward him and then away again or who moves his own hand toward his eyes and away in a cyclic pattern. These events provide information for the constant size of an object. Like many of the events that follow, they are reversible in a special sense, because the transformation that restores the initial state is similar to the original transformation.

Another type of reversible event gives information for so-called shape constancy. An object that turns or rotates provides optical information via a series of continuous perspective transformations for a persisting shape of the object itself. The continuity of the transformation and its reversibility can be duplicated by an observer's walking around an object or turning it in his hand. Such information is picked up by infants quite early.

Information for substance, another persisting property of objects, is also revealed in reversible transformations of different kinds. Rigid objects, when moved, retain constant cross-ratios for points in linear relation on their surfaces, no matter what the angle of rotation. Nonrigid objects may deform when moved, especially when squeezed or subjected to pressure. Cyclic deformation is information for elasticity of substance (rubbery or fluid transformations) and is also picked up early. (For experiments on the development of size and shape constancy and detection of substance, see *Obtaining Information About Objects*.)

Reversible paths in a layout that can be walked through provide a continuous series of reversible vistas that give information for an objective, permanent environment in which objects and oneself can move around (see *Obtaining Information About Places*). As one moves, surfaces are occluded and disoccluded—a most important reversible event that provides information for persisting properties of both objects and the layout. Looking at a landscape through a window, one perceives a continuous lawn or expanse of terrain. Much of this expanse is occluded by trees, buildings, and so on, but we perceive that the full expanse is there. We can procure direct information for it by moving our viewing position so that what was concealed is revealed.

An irreversible event is one for which there exists no transformation, in the ordinary world, that will restore the event's initial state. Irreversible transformations hold information for nonconstancy or change of state. They occur in events like evaporating, breaking, and being consumed. Infants do not experience many such events until the beginning of the second year when they not only witness but also create events such as spilling milk, breaking toys and dishes, and consuming cookies.

There has been rather little research on the child's differentiation of reversible and irreversible events and perception of their affordances. Bower's experiment (1967a) comparing a perspectival with an implosive disappearance is one. Another method has been developed to study the perception of reversibility and irreversibility in more complex natural events. Gibson and Kaushall (1973) filmed events that were reversible and irreversible and presented them in pairs, one projected correctly and one with the film reversed. Adults perceive the irreversible event (e.g., spilling ink on a blotter) as absurd when the film is run backward. The method was adapted for children by Megaw-Nyce (1979). Films were prepared of events that were thought to be natural for young children (e.g., bouncing a ball, breaking an egg, spilling milk) and were shown to 4 year olds, first correctly projected and then reversed. Half the filmed events were deemed (by adults) reversible-event sequences and half irreversible. When the reversed films were shown, the children were asked whether the event was one they had been shown before (the same as one they had seen) and then whether the event was possible or was magic. The children were aware of the distinction between reversible and irreversible events; they noticed no change in the reversible ones but made it clear that a change in the order of the irreversible ones altered the meaning as a real and possible occurrence. It seems likely that information about persistent properties of things is picked up in

continuous cycles of reversible events long before 4 years (e.g., information for constancy of size and shape).

Experimental paradigms for the study of perception of persisting properties of objects, places, and events over reversible transformations are variously referred to as investigations of constancy, object permanence, identity, or conservation. Two of these, object permanence and conservation, imply more than perceiving a persistent property because the terms are generally used to imply conceptual knowledge. They are discussed in other chapters (see *Gelman & Baillargeon, vol. III, chap. 3; Mandler, vol. III, chap. 7; Harris, vol. II, chap. 9*). It is worth pointing out, however, that even conceptual knowledge about persistence is rooted in observations of reversible events.

Reciprocity

Social events are especially rich sources for studying event structure, especially in early social interchanges. The many studies of mother-infant interaction in recent years have emphasized again and again the reciprocity of interaction within these events, cycles of turn-taking (Brazelton, Koslowski, & Main, 1974). This interaction foreshadows the development of event perception more generally, for example, in game structures.

Peekaboo is perhaps the earliest game in which infants typically take part, and a reciprocal rule structure as well as articulated substructure (disappearance and reappearance) is found in almost anybody's version of the game (see Bruner & Sherwood, 1979). The reciprocal relations and the articulated points of subevents are perceived as early as 4 months (Greenfield, 1972). Infants do not usually control the game until later, but the structural relations are picked up. It is interesting to note that the actions in this game are both reciprocal and reversible and that discovery of this structure is enjoyable. The degree of embedding of substructures is kept to a minimum in this nursery game (as in others, like patacake), demonstrating the commonsense knowledge of parents and caretakers that simple, repetitive event structure is appreciated early and that deeper embedding (like story structures) is appreciated only later in development.

Nonreciprocal events may also provide information about social encounters—encounters in which different participants assume different roles. This information can even be portrayed without any pictorial information about the participants' features. Movies made by animation techniques that depict abstract figures, like circles and squares, moving about can lead to perceiving actions of one person or another, such as pushing, running, following, fighting (Bassili, 1976). Such movies can also depict people with distinct personalities, moods, and social roles (Heider & Simmel, 1944).

Causal Structure

Perception of causal relations in events has long been a topic for dispute among philosophers and psychologists, the disagreement taking place along typical lines: Is a causal relation inferred only as the result of interpretation based on past experience or is it perceived directly? The first view is historically attributed to the philosopher Hume, although a different version of this view has been suggested by Piaget. Piaget did not believe that causality was immediately perceptible but thought that it developed with age and was based on the development of action (see Piaget, 1969, pp. 234ff., for his interpretation of Michotte's [1946/1963] experiments; see E. J. Gibson, 1969, for a discussion of Piaget's views on causality and experiments performed by his collaborators).

The second view was developed by Michotte (1946/1963), who spent much of his life as a psychologist studying the perception of causality. Michotte was interested in causal events of a mechanical nature, like one billiard ball hitting another and sending it off on a path with a velocity that is specified by conditions attending the collision. Michotte studied several such events (e.g., launching, triggering, and entraining), simulating them with ingenious displays on rotating cardboard discs that were not, however, very lifelike (see Runeson, 1977). Adult viewers described the event relations in these displays as causal and so, on the whole, did young children (Olum, 1956, 1958), although children segregated parts less within the event. Perceived causality, Michotte (1946/1963) pointed out, was amodal, in that no specific sensory experience attended it. Piaget took a third view of the perception of causality.

Research with very young children on perception of causal relations of a mechanical type is rare. Keil (1979) studied the development of anticipation of the outcomes of causal events in children 1½ and 2½ years old. The events involved removal of crucial supports from a block structure. Anticipation was measured by degree of surprise when a causal relation was violated. When an object lost its support but remained suspended in midair, children of both ages showed surprise. The event itself was meaningful for the younger group if viewed as a whole, but not if presented as two static before and after displays when some kind of inference was presumably necessary.

Younger infants (9 to 12 weeks) were tested by Ball (1973) in an investigation of perception of a simulated causal relation somewhat like Michotte's (1946/1963) demonstrations. A red Styrofoam object disappeared behind a screen and then a white object emerged from the other side, with a delay and velocity appropriate for a concealed collision to have taken place. Infants were habituated to this condition. Then half the subjects witnessed 10 trials in which a red object collided with a white one, whereas the other half witnessed motion of the two objects (red toward white followed by motion of white) without any contact (no continuity of motion). There was no concealment in these cases. Infants in the noncollision, no-contact condition tracked the display longer during the test trials. Ball interpreted his results as supporting those of Michotte, in that perceived continuity of motion (despite occlusion) was presumed to be an essential condition for perception of a mechanical causal relation. An experiment by Borton (1979) investigated whether 3-month-old infants could distinguish between a causal and a noncausal event. There were three events: (1) a single object moving across a horizontal track; (2) one object moving toward a second stationary one, colliding, and launching it; and (3) the first object approaching the second but stopping short of collision as the second moved off. Disrupted tracking was more apparent in the noncontact than the contact condition. There were no differences between the contact and the single object conditions. Spatiotemporal continuity of movement seems again to be a distinguishing feature for the infants. But it is not clear in either of these studies whether the mover object was perceived as a separate object from the one moved. To perceive that one object causes a change in another, the two objects must be distinguished from one another.

Mechanical events are only one type of causal relation. Self-controlled events, often characterized as intentional, are another type, and, indeed, have often been considered as providing the most primitive experience of causality from which other types (use of tools, perceiving others as agents, mechanical causality) are eventually differentiated. Such, in essence, is Piaget's (1953) view. An infant begins with primitive causality, a feeling of efficacy linked with his own activity. There is a progression from egocentric causality to spatialization of causality, which means perceiving external objects in causal relations of the kinds we have just described.

Self-controlled events are of great interest to infants, whether or not they are perceived as intentional, and these events may enter into development of the perception of causal relations in ways different from that envisaged by Piaget. Piaget's secondary circular reactions (see *Harris, vol. II, chap. 9*) testify to infants' interest in self-produced events and their affordances. Even more dramatic testimony is provided by experiments performed over the last decade on infants' perception of contingency and the apparent reinforcing effect of self-initiated contingencies. Examples are so plentiful in the infant literature that it is hard to choose one. Papoušek may have been the first to show that infants would suck contingently, long after hunger was appeased, apparently for the pure motive of controlling a predictable event contingent upon their own behavior (see Papoušek, 1979, for a recent discussion; also see *Exploring and Attending*).

Other examples show how perceived contingency enters into discoveries about control of one's own actions and their consequences. Watson (1966, 1972) observed head and limb movements of infants in response to a stimulus display that changed contingently with their actions. Infants of 2 to 3 months discovered the contingency and increased their own movements to produce a change in what they saw. Moreover, increasing awareness of a clear contingency produced vigorous smiling and cooing, leading Watson (1972) to refer to such a sequence as "the game." The critical condition here seems to be the interplay of perceived control and a changing event sequence. The contingent change, whatever it may be, is related to the infant's activity, as is the change when an adult guides the path of a car by turning a steering wheel. The wheel, when turned, brings into view a changing path with new affordances. Infants, like adults, are motivated to explore events that they can control—to monitor the outcome of their own actions and look for their utility. The continuous interplay of acting and perceiving can bring to light the affordances of events.

A third (but basically similar) kind of causal relation is the use of tools to effect some desired consequence. Selection and use of a tool depends on perceiving the affordance of the tool (J. J. Gibson, 1979). The affordance is perceived, in the first place at least, within an event structure. Classic examples of perceiving the affordance of tools are found in Köhler's *The Mentality of Apes* (1925). Apes, like people, may discover that sticks can be used as levers, as jumping poles, and as extensions to one's arm to obtain a desired out-of-reach object.

Premack has also emphasized the ape's knowledge of causality (Premack, 1976; Premack & Woodruff, 1978) with tasks showing that a causal relation is perceived between a tool and some antecedent and end state (a knife and a cut apple for example). Chimpanzees presented with a whole apple and then with a cut apple were able to choose the correct tool (a knife) from a collection containing a pen, a nail, an eraser, etc. There was evidence that a transformation was perceived and that the tool for effecting it was recognized—a cause-effect relation. Similar experiments with positive results have been performed with 3- and 4-year-old children (Gelman, Bullock, & Meck, 1980).

Human youngsters may begin to perceive the affordance of tools as soon as they manipulate a mobile toy and perceive a contingency between their own actions and the ensuing event, but exploration and experiment with toys and utensils leads to more explicit knowledge (see *Affordances: Perceiving for Some Purpose*). Children will use a rake to reach a desired toy around 14 to 16 months. They will rotate a moveable surface to obtain an object resting on it between the ages of 16 and 18 months, the ages being quite similar across several cultures (see Dasen et al., 1978).

Speech as an Event: An Example

Spoken language occurs in a stream over time and presents us with all the essential features of an event. The change is mainly over time rather than spatiotemporal, but the changes are relational and invariant properties are retained. Speech events occur in units, and they are structured and bounded. The units are segmented so that small ones are embedded in larger ones in relations of greater or less depth. Speech events have affordances for behavior, the most general one being communication, but they may be of many degrees of specificity. Finally, linguistic events, including speech, are not merely passively perceived, but they are created by the observer in an active fashion. Active perception may not be so obvious in listening to speech, although some prominent theories of speech perception are active ones (Walthen-Dunn, 1967), but activity is obvious in reading written language, where the perceiver moves his eyes over the page to create the sequencing of the event. We cannot go into development of the perception of language, but we will illustrate how speech fulfills our definition of an event and is perceived as one.

Speech is the first form of language perceived by the infant, and it appears to be an event with meaningful affordances from the beginning, although these change toward greater specificity rapidly. Speech is attended to strongly and preferentially, it would seem, from birth. Alegria and Noirot (1978), in an experiment similar to some described earlier (see *Exploring and Attending*), investigated neonates' responses to speech sounds, monitoring head movements, opening of the eyes, mouthing, and crying. As in other studies, they found significantly more head turning in the direction of speech sounds than in the absence of them. They also noted that the eyes opened when the head turn was elicited by speech. The voice also enhanced mouthing and crying, as if the infant expected to be able to suck. Onset of crying took place most frequently when the infants were facing the source of sound and when preceding head movement had led to an approach. When natural nonspeech sounds are presented (e.g., a faucet turning on or a door slamming), infants also turn their heads, but they are less apt to open their eyes or suck (Alegria & Noirot, 1982).

Newborn infants will suck for contingent auditory stimulation, provided by tapes of folk songs (Butterfield & Siperstein, 1972), whereas contingent white noise is ineffective. And in a recent study that allowed neonates to suck in either of two different ways to produce the voice of the mother or a stranger, it was reported that infants modify their sucking specifically to hear the mother (DeCasper & Fifer, 1980). This study indicates that infants begin to recognize the mother's voice soon after birth and that human speech, especially the mother's speech, is an effective motivator for them.

What aspects of human speech might be differentiated by the human infant at such an early age? The more global structural features of auditory events would seem to be likely candidates, such as rhythm (Condon & Sander, 1974), frequency variation (Butterfield & Siperstein, 1972; Eisenberg, 1970), and intonation. Intonation is particularly interesting because intonation and stress carry so much information for sophisticated linguistic structure, both semantic and syntactic. E. L. Kaplan presented 4- and 8-month-old infants with repetitions of a three-word sentence in either rising or falling intonation (E. L. Kaplan, 1969; see also Kaplan & Kaplan, 1971). An habituation procedure was used, with cardiac and behavioral measures. At 4 months, the intonations were not differentiated by this method, but at 8 months they were.[2] An experiment by Morse (1972), however, found positive evidence for discrimination of a rising from a falling intonation in infants from 40 to 54 days of age, using a nonnutritive conjugate sucking procedure. The speech sample presented was a single syllable.

An experiment by Mehler, Bertoncini, Barriere, and Jassik-Gerschenfeld (1978) found evidence of differentiation of intonation in connected speech at 1 month. The infants were reinforced, contingent upon nonnutritive sucking, with either their own mother's voice or that of a stranger. In each case, there was one condition in which the speech was aimed at communicating with the infant and one in which the speech lacked prosodic and intonational qualities of natural speech (the speaker read from a text, backward). Infants sucked more for the mother's voice than the stranger's, but only when the speech contained natural intonation. The stranger's voice also elicited more sucking when naturally intoned.

Intonation over a continuous speech event thus appears to be perceived early, demonstrating pickup of structural relations over a temporal stream. One can ask, then, about the other side of the coin: To what extent is the speech event segmented? There is now ample evidence that very young infants discriminate many phonemic contrasts categorically, in the so-called speech mode (Jusczyk, 1979). But that is not the same thing as segmenting a continuous speech event into meaningful subunits. Such differentiation occurs progressively and extends well into the language-learning process. But articulatory substructure may perhaps be differentiated to some extent before meaningful constituent units are abstracted from the total event. A recent experiment suggests that infants 2 months old segment a stream of speech into syllables (Bertoncini & Mehler, 1981). But not until much later are words segmented from the continuous acoustic stream as the semantic information in speech is abstracted. Segmenting sentences into words actually occurs rather late, as does the ability to segment words into phonemic constituents (see Gibson & Levin, 1975, pp. 119 ff.).

Finally, we can illustrate the pickup of invariant relations in ongoing speech events. Phonemes must carry invariant information over multiple tokens for speech to convey the same information over different speakers or even the same voice in different contexts. Perception of invariant relations in phonemic contrasts over varying contexts is sometimes referred to as perceptual constancy and demonstrations of it have been provided by Kuhl (1980). Infants were trained to make a head turn when a background vowel was changed in a speech sample. When infants had learned to respond to the contrast, variations were introduced into the tokens for each category by introducing changes in pitch contour and by presenting tokens produced by different speakers. The subjects continued to respond to the contrast as invariant over these changes, a situation somewhat analogous to responding to melodies as invariant over transpositions. Syntactic and semantic aspects of surface structure of a spoken message can also be transformed radically while maintaining invariant information for a sophisticated listener. These are essential invariants of a speech event, but they are beyond our assignment here.

Reading written language requires as much attention to an event as does listening to speech, and the same syntactic and semantic information (except for the prosodic features of speech) is there to be extracted. Other structured information is also present—graphic and orthographic structure. As in listening, the beginning reader must differentiate contrastive relations in abstract invariants over changing contents. For example, distinctive features permit identification of alphabetic characters and invariant relations permit their recognition over varying typefaces and handwriting. Orthography provides constraints and rules that structure higher order units in sequences of letters that are distributed spatially but that must be processed as an event as well. These constraints are abstracted during the early stages of learning to read, yielding more economical units of processing (see Barron, 1980).

One more form of language, sign language for the deaf, exemplifies a linguistic event, a spatiotemporal event in this case. It has syntactic and semantic invariants as do other modes of linguistic communication, but it has invariant relations in its own mode as well. Information is conveyed by hand shaping and especially by movement. Motion trajectories vary in many ways, but they are structured and abstract. Variations in speaker style, hand preference, and size of the signing space moved through can all change while the essential relations remain invariant.

The structured use of space and movement in space is particularly important in conveying morphological transformations in sign language (Klima & Bellugi, 1979, chap. 12). Elaborate variations of motion trajectory occur when a base morpheme, such as "give," is embedded in an array of morphological transformations, such as "give me," "I give you," "I am giving you." The abstract, invariant character of these transformations is apparent in that signers, given the base morpheme, can differentiate the transformations when they are performed in the dark with only light spots on the shoulder, elbow, and wrist joints of the speaker to carry the information about the motion (Poizner, Bellugi, & Lutes-Driscoll, 1981).

Little is known as yet about how the human infant exposed to signing as his first language develops the ability to differentiate the invariant information in these complex transformations, but such observations as exist suggest that it occurs naturally by pickup of structural relations in the signed gestures, much as a hearing infant exposed to speech abstracts invariants and differentiates distinctive relations in the speech stream, and that progress occurs at about the same rate, with the same timetable (Holmes & Holmes, 1980; Newport, 1980).

OBTAINING INFORMATION ABOUT OBJECTS

Perceiving the Unity and Boundaries of an Object

The world is furnished with objects: unitary, bounded, persisting things—each of a particular substance, shape, texture, and coloring and perhaps a characteristic odor, taste, and sound. At any given time, each object in an array is only partly in view, that is, its back is hidden and even parts of its forward surfaces may be occluded. It may be next to or resting upon other objects, and all these objects rest on a substratum. Adults perceive each object as unitary, bounded, and complete. When and how does a child perceive where one object ends and another object or surface begins?

Three Views

One general account of the adult's perception of unitary objects centers on the concepts of sensation and association. As an object is encountered in different settings, the various sensations evoked by its visible parts will occur at the same time and become associated. An adult perceives the separateness of an object from its background or from an adjacent object because the sensations evoked by one object are highly associated to each other but less associated with sensations evoked by its surroundings. According to this view, young infants should not perceive the unity of an object and should come to do so only as the object is repeatedly encountered in different places.

A second view, offered by the gestalt psychologists, proposes that animals perceive the boundaries of objects in an array in accordance with certain principles of organization (Koffka, 1935; Wertheimer, 1923/1958). Perceivers group together parts of an array that are close together, that are similar, and that move together in accordance with the principles of proximity, similarity, and common fate. They also group together regions that lie within the same closed area, regions whose contours are aligned, or regions that form simple figures in accordance with the principles of closure, good continuation, and good form. These principles allow a perceiver to see an object as separate from the background, as separate from an adjacent object, and as continuing behind an occluder (Koffka, 1935; Michotte et al., 1964). The principles are believed to reflect the structure of the brain and so are thought to be independent of learning.

We shall argue for a third view (Spelke, 1982). A child perceives an object whenever she detects a topologically connected arrangement of surfaces that retains its connectedness as it moves. The arrangement and the movements of surfaces in a scene are richly specified. For example, the separateness of an object from the background is specified, as the object or the observer moves, by the accretion and deletion of background texture at the edges of the object. The unity of a moving object is further specified by the relationship between the movements of its parts. If the object moves rigidly, its projection at the eye undergoes a continuous series of perspective transformations, with all the invariant properties of projective geometry (Gibson & Gibson, 1957). If the object is jointed, such as a person, motions of its parts share a common directional component (Johansson, 1978). Perception of objects depends on the detection of such invariants. Infants and children should perceive the unity of an object as soon as they can perceive the appropriate arrangement and movements of its surfaces.

Objects as Separate from the Background

Studies of reaching provide the best evidence that infants perceive a single object, suspended in front of a uniform background, as a separate whole. Infants begin systematically to reach for objects at about 4½ months (see *Exploring and Attending*). At that time, their reaching is adapted, to some degree, to an object's visually given distance, direction, movement, and size. The size of an object, in particular, could not be registered if the object were not perceived as a separate thing.

Infants of 6 months indicate that they perceive the unity of a visible object in an additional way. They appear to expect that a suspended object can move independently of its background and that the object must move as a whole. Spelke and Born (1982) presented infants with a three-dimensional object in front of a flat surface that began to move toward them in two ways. In one condition, the object alone moved, as a whole; in the other condition, part of the object moved in tandem with part of the background. Infants were judged by a naive observer to be surprised or puzzled when they witnessed the breakup of the object, but not when they witnessed the unitary movement of that object. An infant's surprise may reflect her expectation that an object will move as a whole. Such an expectation implies that she perceives the object as unitary and separate from its surroundings.

It is difficult to investigate the perception of unitary, bounded objects by infants who are not yet able to reach. The studies that have attempted this, however, suggest that the capacity to perceive suspended objects develops very early. It has been shown, for example, that 3-month-old infants will swipe at objects even though they do not reach for them. And like later reaching, their swiping is affected by an object's size, direction, and distance. Furthermore, 3-month-olds, like 6-month-olds, show signs of surprise at movements of an array that break up the boundaries of an object (Spelke & Born, 1982).

Young infants evidently perceive the boundaries of a visible object by detecting the spatial separation between the object and its background, for they do not appear to perceive objects when no such separation is present. Infants show no surprise when a pictured object breaks apart (Spelke & Born, 1982). Infants may perceive the spatial separation of object and background by detecting discontinuities in the velocities of texture elements from the object and background, contingent on head and eye movements. Alternatively, they may detect the accretion and deletion of background texture at the occluding edges of the object, a pattern that is also produced by head movements. In either case, motion would seem to bring information about the boundaries of an object.

Adjacent Objects

Two adjacent surfaces sometimes belong to the same object and sometimes do not. As adults, we perceive adjacent surfaces as connected or separate in accordance with the gestalt principles of organization. Studies of infants suggest that the ability to perceive these connections and separations does not emerge as early as the capacities discussed above.

Piaget (1954) observed the development of one infant's reaching for objects under a variety of conditions. He reported that this infant would not reach for an object on a small support—a box, a book, or the palm of a hand—until 8 to 10 months. The same infant did reach successfully for a dangling object or an object on an extended support. Although recent research suggests that younger infants do attempt to touch supported objects, they reach more directly for an object perched on someone's fingertips than for an object lying on another object (Bresson, Maury, Pieraut-le-Bonniec, & de Schonen, 1977; Bresson & de Shonen, 1976–1977). The young infant's difficulties may stem from problems in motor control. But a more interesting possibility, originally suggested by Piaget (1954), is that the child fails to perceive that a supported object is a unit separate from its support. It is noteworthy that Piaget's infant did reach for a supported object if it moved relative to its support. This motion may have specified the object's unity and boundaries for the infant.

A recent experiment provides evidence that young infants perceive two adjacent objects as one unit. Prather and Spelke (1982) presented one group of 3-month-old infants with a succession of displays each containing one rectangular solid object. A variety of objects, differing in color, shape, and size, were presented in a variety of locations. A second group of infants was presented with a succession of displays each containing two objects of different dimensions but the same color, presented so that they were spatially separated in the frontal plane. The colors, shapes, sizes, and locations of the objects again varied from one display to the next. It had previously been shown that infants can be habituated to the number of objects in an array (Starkey, Spelke, & Gelman, 1980; Strauss & Curtis, 1981). It was hoped, therefore, that infants in this experiment would habituate either to one-object or to two-object displays.

After habituation, infants in both groups were presented with two objects that had not been shown previously; they were of the same color but different shapes. These objects were presented in a one-object and a two-object display to determine if infants would dishabituate to a change in number. In addition, the objects were presented in two new configurations. In one display, they were adjacent, side by side. In the other display, they were separated in depth—one object stood directly in front of the other and partly occluded it so that their projections at the eye overlapped. Many infants did not show the predicted dishabituation to a change in number. Among those who did respond to number, most of the infants who had been habituated to one-object arrays showed greater dishabituation to the

objects separated in depth, and most of the infants habituated to two-object arrays showed greater dishabituation to the adjacent objects. It appeared that the infants perceived two adjacent objects as one unit and perceived two objects separated in depth as two units. This experiment suggests that the ability to see two adjacent objects as separate develops after 3 months. Young infants may not perceive object boundaries in accordance with the principles of good form and good continuation.

Partly Occluded Objects

When—and how—do infants perceive the complete shapes of partly hidden objects? Research by Michotte et al. (1964) suggested that adults perceive partly hidden objects in accordance with the principles of good continuation and good form. An experiment by Bower (1967b) suggested that some of these principles are effective for infants as well. Infants 6 weeks old were conditioned to suck in the presence of a wire triangle with a long, vertical cylinder suspended in front of it and partly occluding it. Sucking generalized to a complete triangle more than to a variety of other displays. Infants appeared to perceive the unity of the triangle. This ability was not evident, however, in a further experiment by Bower (1967b) in which infants viewed a two-dimensional representation of the occluded triangle.

Infants' perception of occluded objects was investigated further in a series of experiments (Kellman & Spelke, 1979, 1981). In one experiment, 4-month-old infants were habituated to a straight rod whose center was occluded by a block, and then they were tested with alternating presentations of a complete, nonoccluded rod and a rod with a gap where the occluder had been. The infants looked equally to the two test displays. Their equal looking did not reflect a failure to discriminate the test rods; infants in two control experiments, presented with the same test displays after habituation to a nonoccluded complete or broken rod, looked longer to the test rod they had not seen. Moreover, infants habituated to a partly occluded rod looked longer to a new rod display with a gap larger than the area where the occluder had been. It appears that infants in the original experiment perceived the two visible ends of the original, partly occluded rod neither as definitely connected nor as definitely separate. In a further experiment, infants were presented with a partly occluded triangle very similar to that used by Bower (1967b). Habituation to this display also generalized equally to complete and broken triangle displays. Thus, the gestalt principles of good continuation, good form, and similarity did not jointly lead infants to perceive a unitary object.

In the next experiment, infants viewed the partly occluded rod and block display, but now the rod moved. In one condition, the visible parts of the rod moved in tandem to the left and to the right. In other conditions, the rod and block moved together as a unit or the block moved while the rod remained stationary. The center of the rod never came into view during these movements. After habituation, infants who had viewed the rod moving against a stationary block looked more to the broken test rod. The other infants looked equally to the two test displays. It was concluded that infants do perceive the unity of similar, aligned ends of a partly hidden object if the ends move together independently of the other surfaces in the scene. Subsequent studies revealed that any translatory movement through a scene—movement in depth as well as lateral movement—provided information to infants that the ends of the rod were connected behind the occluder (Kellman & Spelke, 1981).

A final experiment investigated whether infants would perceive the unity of two parts of an object that moved together if the parts were not similar in color, texture, or shape and were not aligned. Two different nonaligned objects protruded from behind the same occluding block and moved together. After habituation, infants viewed these objects without the block, connected or separated. A separate experiment indicated that the two test displays were equally attractive to infants. But infants who had habituated to the objects moving together looked longer to the display of separated objects. Infants, thus, seem to perceive a unitary, partly occluded object when its visible parts move as a whole, even when the principles of similarity and good continuation work against that impression for an adult.

In sum, the unity and bounds of an object might be specified for a young infant only by its spatial separation from other things and its movement relative to those things (Spelke, 1982). Infants may not perceive the separateness of two stationary, adjacent objects because the boundary between them is specified only by their dissimilarity and nonalignment. Infants may fail to track an object moving in tandem with its background (Harris et al., 1974) because an object and background are perceived as a single unit when they move together. Finally, Piaget's (1954) infant might not have been able to reach for a supported object unless it moved relative to its support because the independent motion of object and support specified that they were separate. Neither association theory nor gestalt theory can easily account for these findings. The boundaries of objects are first given in events.

Perceiving the Properties of an Object

Objects have many affordances for a perceiver. The potential affordances of an object depend on such properties as its substance, texture, and shape. Many of the properties of an object are specified to more than one perceptual system. We focus here on some of the more important amodal properties of objects.

Substance

Objects can be rigid or flexible. If rigid, they can be brittle or strong, solid or hollow, and made of such substances as stone, wood, bone, or metal. If flexible, they can be fuzzy or elastic, stretchable or deformable, and made of such materials as rubber or fur. Objects can also vary in density and, thus, in weight. When do children begin to perceive these properties and their affordances?

Infants have been found to differentiate between rigid and flexible objects visually, aurally, and haptically in a coordinated fashion. A series of studies has investigated visual perception of rigid and flexible objects. In the first (Gibson, Owsley, & Johnston, 1978), infants of 5 months were presented with a sponge-rubber object undergoing three different rigid motions. These presentations continued until visual attention had habituated, then new events were presented for several test trials. On some trials, the object was seen to undergo a fourth rigid motion. On others, it was seen to undergo a deforming motion. The subjects dishabituated to the deforming motion, whereas presentation of a fourth rigid motion yielded results similar to a no-change control condition. In subsequent studies, infants of 3½ months were shown to respond to invariant information for rigidity over a class of rigid motions even as the objects undergoing these motions changed in shape (Gibson, Walker, Owsley, & Megaw-Nyce, 1979). They were also shown to habituate to a class of deforming motions and to dishabituate to a new rigid motion (Walker, Owsley, Megaw-Nyce, Gibson, & Bahrick, 1980). These studies indicate an early sensitivity to optic information for the rigidity or flexibility of an object.

The substance of an object can be specified haptically and aurally as well as visually. Infants are sensitive to some of these sources of information as well, and they detect correspondences between visual and aural information for the substance of an object. Bahrick (1980) investigated auditory-visual perception of substance in 4½-month-old infants. Infants were presented with films of two events. In one, two wooden blocks repeatedly struck each other, producing a clacking sound. In the other, two wet sponges struck each other, producing a squishing sound. Infants viewed the films side by side, accompanied by one synchronized sound track played through a central speaker. In one condition, each sound was synchronized with the movements of the appropriate object. In a second condition, each sound was synchronized with the inappropriate object, that is, squishes accompanied the impacts of blocks and clacks accompanied the impacts of sponges. Infants looked preferentially to the aurally synchronized object only if the motion of that object provided information for the same substance as was specified by the sound. This study and others (see Bahrick, 1980) suggest that infants detect information for rigidity and flexibility both by looking and by listening.

Haptically, infants of 12 months differentiate objects of rigid and elastic substance by handling them differently. Rigid, hard objects are banged on available surfaces (a tabletop or another object). Elastic, spongy objects are squeezed, pressed, and wiped on surfaces rather than banged. Following handling an object of a hard or an elastic substance, infants looked preferentially at a film of an object of the familiarized substance moving in an appropriate pattern (Gibson & Walker, 1982). As noted earlier (see *Exploring and Attending*), even 1-month-old infants appeared to differentiate rigid from flexible substances during oral exploration: they detected a correspondence between a rigid or flexible object in the mouth and an object moved rigidly or flexibly in a visual presentation (Gibson & Walker, 1982).

These studies suggest that infants can perceive one aspect of the substance of an object and that they do so as the object participates in events. It is not known whether infants can perceive other aspects of the substance of an object. Although they differentiate rigid from nonrigid objects, they may not be sensitive to differences among classes of rigid or nonrigid objects, differentiating wood from glass or metal or rock, differentiating a person's skin from cloth or rubber, and so on. But they do appear to perceive one other aspect of an object's substance very early, its weight.

When an infant in the second half-year picks up an object, he adjusts the tension in his arm to the object's perceived weight (Halverson, 1931). Furthermore, such an infant can use vision to provide information about an object's weight. An infant of 9 months or more who is handed the same object repeatedly will come to anticipate the muscle tension needed to hold it (Mounoud & Bower, 1974). If a larger object is then presented, an infant of 15 months will increase the arm tension, as if expecting the larger object to weigh more. Such an infant can be fooled by changes in the visual appearance of an object. If a spherical ball of clay, repeatedly held by the infant, is flattened into a pancake, the infant seems to anticipate that it will weigh more; he increases the tension in his arm as it is handed to him and his arm flies abruptly into the air. By 18 months, the infant no longer makes this error: he comes to appreciate that the weight of an object is invariant over changes in its shape (Mounoud & Bower, 1974). Five or six years pass before the child comes to use this information when he makes explicit judgments about the weights of objects (Piaget & Inhelder, 1941). Perhaps the perceptual invariance that is detected at 18 months only later becomes accessible to thought.

Texture

The surfaces of objects can be rough or smooth, hard or soft, finely or coarsely grained. These distinctions can be perceived visually and haptically by adults. Some properties of texture are also detectable by infants. As noted in our earlier discussions, 6-month-old infants discriminate haptically between objects of different textures (Steele & Pederson, 1977). Infants of this age can also perceive the constant texture of an object over changes in its color (Ruff, 1980). After habituation to a series of differently colored objects, all with the same texture (depressions or protrusions in its surface), infants dishabituated to a new object of a different texture but not to one of the same texture. Finally, it is possible that very young infants perceive texture intermodally by mouthing and looking (see *Exploring and Attending*).

Infants evidently can perceive aspects of an object's texture both by vision and by touch, and they can coordinate visual and haptic information about a texture. It is not clear, however, how sensitive infants are to texture differences. Adults are very sensitive to small changes in the roughness of texture, both visually and haptically (Bjorkman, 1967). The development of this sensitivity has not, to our knowledge, been studied.

Shape

Very young infants discriminate visually between flat and solid objects (Cook, Field, & Griffiths, 1978; Fantz, 1961; J. Field, 1977) and between many pairs of objects that differ only in shape (see Ruff, 1980, for a review). But perceiving the characteristic shape of an object requires more than these accomplishments reveal. One must perceive the shape as constant over changes in its orientation, and over the resulting projective transformations at the eye. This, in turn, would seem to require that the infant perceive the orientation of an object in a three-dimensional layout, detecting stimulus relationships that remain constant as the orientation of an object changes. Research now indicates that young infants can perceive the constant shape of an object.

The first evidence for shape constancy in early infancy was provided by Bower (1966). Infants of 2 months were conditioned to turn their heads in the presence of a rectangular surface presented at 45°; generalization was tested with several rectangular and trapezoidal surfaces at several orientations. Infants responded more to the real shape, even when it was presented in a new orientation. Positive evidence for shape constancy in the first 4 months has also been reported by Day and McKenzie (1973) and by Caron, Caron, and Carlson (1979).

Studies of infants do not indicate how precise the perception of shape is. Experiments with children, using judgment methods, have investigated developmental changes in the precision of shape constancy. Such research suffers from certain methodological problems (for discussions, see E. J. Gibson, 1969; Piaget, 1969; and Wohlwill, 1963)—when age differences are found, it is rarely clear whether they are caused by developmental changes in the constancy mechanisms themselves or in other judgmental processes. Nevertheless, there appear to be few age changes in the precision of shape constancy. For example, Meneghini and Leibowitz (1967) and Kaess, Haynes, Craig, Pearson, and Greenwell (1974) presented children and adults with textured, flat objects of different dimensions at different orientations. Children were told to pick the frontal comparison object that matched the shape of the standard. There was no improvement with age on shape judgments when the standard and comparison objects were presented at the same distance. In the Kaess et al. (1974) study, shape constancy was equally high from age 4 to age 19, whereas in Meneghini and Leibowitz's study (1967), shape constancy was most accurate at the youngest age. Govorova (cited in Venger, 1977) reported similar findings using a different procedure. Shape-constancy judgments did improve with age when the standard object was presented at five times the distance of the comparison object. This age difference may reflect a tendency for younger children to be less attentive to objects at farther distances or less able to compare two objects presented at different distances.

As children grow, they come to differentiate shapes of ever greater complexity. Developmental changes in haptic shape perception are especially marked. By 10 months of age, infants have been found to discriminate and recognize certain simple shapes that they have explored manually. Soroka, Corter, and Abramovitch (1979) presented infants with one solid object in the dark for 2 min. Then, the infants were given the same or a differently shaped object. Infants manipulated the novel object for a longer time; they evidently could recognize the familiar one. In addition, infants of 8 to 12 months have been found to recognize visually an object they have felt (Bryant, Jones, Claxton, & Perkins, 1972; Gottfried, Rose, & Bridger, 1977), but this ability has not always been found with 6-month-old infants or with 1-year-old infants of low socioeconomic status (Rose, Gottfried, & Bridger, 1978). Although these failures may reflect only the insensitivity of current tests of tactile recognition, it seems likely that the ability to perceive shape manually develops slowly over the course of infancy along with the development of haptic exploration (see *Exploring and Attending*).

Young infants may have difficulty perceiving the shapes of objects if the shapes are complex and if other properties vary. Ruff (1978) presented 6- and 9-month-old infants with two objects, each of which was a unique combination of cubes, blocks, spheres, and cylinders. One shape was presented at a variety of orientations, positions, and colors; in some conditions, an object was seen to move, whereas in others it was not. After a series of familiarization trials, discrimination was tested with familiar/novel shaped objects. Infants of 6 months did not appear to recognize the familiar shapes as the same when presented with an object of a new color, size, and orientation. Infants of 9 months did recognize the familiar shape under some conditions but not under others.

Visual shape perception continues to develop throughout childhood (see *Exploring and Attending*). Preschool children do not explore the contours of objects as consistently as older children, and they perform less well on visual- and haptic-matching tasks (Zaporozhets, 1969; Zinchenko et al., 1977). Young children also have difficulty with certain tasks involving simple shapes.

Zaporozhets (1969) presented children of 6 months to 3 years with a form-fitting problem. A child was shown a board with two apertures of the same shape standing in front of two objects of different shapes. Both apertures were the same shape as one of the objects. The child could obtain that object by reaching through the aperture and pulling the object through the opening. The other object could not be obtained in this way. Children attempted to obtain these objects on a series of trials. Initially, they all approached this task by trial and error, reaching for both objects. Children of 2 years eventually learned to take account of the shape of the object, reaching only for an object of one particular shape, but they continued to reach for that object after the aperture shape was changed. These children never learned to take account of the relationship between the shape of the object and the aperture. Older children do take account of this relationship.

It seems that the younger children could not perceive the relationship between the shape of an object and the shape of the corresponding aperture. Possibly this task was difficult because the young child cannot abstract one aspect of an object's shape, its two-dimensional silhouette. The young child may be able to perceive the shapes of blocks but may have difficulty deciding whether an object's outline shape at its greatest extension corresponds to the outline shape of the aperture.

In summary, young infants have certain limited abilities to perceive shape. They can discriminate and recognize simple shapes but not complex, embedded ones. They have a capacity for visual-shape constancy, although it is not clear how accurate their shape constancy is. They are not adept at perceiving shape haptically, especially through active manipulation. Finally, their capacity to perceive shape may be functional for some purposes, such as discriminative responding, but not for other purposes, such as object-aperture matching of one contour. As children grow, they explore more effectively shapes of greater complexity and embedding, and they may perceive more subtle relationships among the shapes of solid objects.

Size

As noted in our earlier discussion, *Exploring and Attending*, infants of 3 months differentiate between an object of graspable size and an object too large to grasp (Bruner & Koslowski, 1972). Infants, thus, respond to some degree to the size of an object, perhaps in relation to the size of the hand. To perceive the sizes of objects flexibly and adaptively, however, one must perceive their sizes as invariant over changes in distance. Bower (1966) investigated this capacity for size constancy in early infancy. He conditioned 6- to 12-week-old infants to turn their heads in the presence of a 12-in. cube 3 ft. away. The cube was placed on a table in a room whose walls remained visible. Thus, a perceiver could, in principle, assess the object's size by taking account of its distance, or she could perceive its size relative to the width of the table. Generalization testing was given with cubes of several sizes and distances. Generalization was greatest to a cube with the same true size at a new distance, even though that object now subtended a much smaller angle at the eye. Bower concluded that infants innately perceive size as constant over changes in distance.

Although a number of subsequent experiments failed to provide evidence for size constancy (Day & McKenzie, 1977), such evidence has recently been obtained. Day and McKenzie (1981) presented 4-month-old infants with an object that moved continuously through a limited range of distances from four different starting points. After habituation, infants were presented with the same object as well as with an object twice or half its size that moved through the same range of distances. Habituation generalized to the moving object of the same true size, despite the change in the angle it subtended at the eye.

These studies indicate that some capacity for perceiving size over changes in distance appears very early in life, but they do not indicate how precise the infant's size constancy is. Studies of children have addressed this question.

The literature on the development of size constancy in children is long and complex (for reviews, see E. J. Gibson, 1969; Piaget, 1969; Wohlwill, 1960). Depending on the stimulus and task conditions, many different patterns of developmental change have been obtained. Four conclusions, nevertheless, appear to be established. First, at the youngest ages tested, judgments of real size are far more accurate than judgments of projected size, insofar as the latter can be tested (Brunswik, 1956; Piaget, 1969). Second, evidence for size constancy is obtained at very young ages under conditions that do not require verbal judgments (see E. J. Gibson, 1969; Tanaka, 1967). Third, judgments of size over changing distance improve, at all ages, when objects are presented on a richly textured ground. The benefits of a textured ground suggest that children detect information for a continuous spatial layout and use this information in perceiving object size. Finally, there is, in some situations, a tendency toward increasing over-constancy with age. Over-constancy may reflect a bias in the child's judgments rather than her perceptions (Wohlwill, 1963). On the other hand, it may result from a change in the information used in a size-constancy task (Sedgwick, 1980).

Animacy

Animate objects differ in many ways from inanimate objects, and there is some reason to think that they are differentiated very early in life (see Gelman & Spelke, 1981, for a preliminary analysis of these differences and the child's appreciation of them). Brazelton et al. (1974) compared infants' responsive behavior to an inanimate object (a toy monkey suspended on a wire) and to a person. At 6 weeks, the infants stared fixedly at the toy and followed it with the gaze when it was moved to one side or the other. Fingers and toes appeared to point jerkedly at the object. Attention was intense and rapt. But when the person (the child's mother) was the object, attention occurred in cycles of alternating interest and withdrawal as if the infant expected a response from the object. Trevarthen (1977) reported similar differences between the infant's response to a person and a toy. In particular, he noted that expressive behavior and gesturing were much more frequent in the presence of the person.

A young infant not only seems to expect other people to respond to him, he may become upset if this expectation is not fulfilled. Such reactions have been reported many times (see Bloom, 1977; Brazelton et al., 1974; T. M. Field, 1979; Fogel, Diamond, Langhorst, & Demos, 1979; Trevarthen, 1977). For example, Tronick, Adamson, Wise, Als, & Brazelton (1975) observed infants of 6 to 16 weeks in interaction with the mother. On cue, the mother was instructed to become unresponsive. Infants of all ages were distressed by this manipulation. These findings suggest an early differentiation of animate from inanimate objects and an early appreciation that animate objects respond to one's acts.

Responsiveness is certainly one of the essential affordances of an animate object, and many authors have written of the importance of a responsive environment for normal development. Infant monkeys deprived of social rearing with members of their own species may be at a disadvantage in later dealings with their environment, but any responsive environment, even the company of a dog, appears to be better than a nonresponsive one, however comfortable otherwise (Mason, 1978). Responsiveness is a characteristic of objects that is revealed only in events, especially those contingent on the infant's own actions.

Animate objects are not only responsive, they move differently from most inanimate objects. Inanimate objects for the most part move rigidly; animate objects do not. Some animate objects, like worms, move only in cycles of deformation; some, like vertebrates, have a rigid skeleton and can move the limbs rigidly like levers, but they are jointed and so the total skeletal movement is deforming, as is the movement of the musculature (particularly noticeable in faces). These differences may be detectable to infants. Several recent studies suggest that infants early in the first year discriminate changes in structure in dynamic light patterns representing biological motion that are not discriminated in successive static displays. Bower (1982) reported that infants discriminated gender in moving point-light displays; Bertenthal and Proffitt (1982) and Fox and McDaniel (1982) reported that infants discriminated moving-light displays of walkers from other displays of nonbiological motion.

Perhaps above all, the source of motion of an animate and an inanimate object is different. Animate objects can move from within, in the absence of any external force. Inanimate objects move only when some force is applied. Thus, animate objects provide a different type of information for perception of causal events than inanimate objects, and this difference could serve as a further basis for distinguishing these kinds of objects. We have already noted that infants may be sensitive to some information for a causal relationship (see *Obtaining Information About Events*). Moreover, preschool children have been observed to refer to the causes of an object's movement when they are asked whether a toy with certain animate features (a doll or a puppet) is capable of walking, talking, thinking, and so on. Most children judge that dolls cannot walk, for example, "unless someone moves it" (Gelman, Spelke, & Meck, 1982).

Overview

There are modality-specific properties of objects, such as color, temperature, and scent as well as the properties described above. Infants and young children are known to be sensitive to some of these (see *vol. II, chaps. 1 and 2*). But the above examples should serve to illustrate a few general principles. First, very young infants have rudimentary abilities to perceive the properties of objects. They are sensitive to stimulus information that specifies the substances, textures, shapes, sizes, and perhaps the animacy of objects. Second, perception of objects becomes increasingly differentiated as children develop strategies of exploration and manipulation. Third, objects are first perceived, and best perceived, when they participate in events. And, in events, their most important affordances are revealed.

Reactions to Conflicting Visual and Haptic Information

We have reviewed evidence suggesting that young infants perceive the unity of an object they see and hear or see and feel. They can coordinate auditory and visual information about the location, movement, and substance of an object as well as visual and haptic information about its shape. We have also reviewed evidence suggesting that the earliest actions, such as reaching, are guided by an object's visually given distance, direction, motion, size, and shape. These early coordinations suggest that perception of the unity of a multiple specified object depends not on associative learning or on the integration of action schemes but on the perception of object properties and affordances.

Yet one source of evidence seems to contradict this conclusion. A number of experiments have been conducted in which visual and haptic or visual and auditory information have been made to conflict. The reactions of infants to these conflicts have been observed. If different modalities are coordinated with each other and if perception is truly coordinated with action, then infants might be surprised or distressed when intermodal and perceptual-motor relationships are altered. In most cases, young infants do not respond noticeably to such rearrangements.

In a series of ingenious studies, Bower (Bower, 1974; Bower et al., 1970a, 1970b) presented infants with the visible image of an intangible object. Using a stereoscopic shadow caster he was able to create what for adults is the visual impression of an object suspended within reach. When the infant extended her arm, however, she encountered empty space. Bower et al. (1970b) reported that 1-week-old infants became distressed when their reach did not lead to contact with an object. Older infants (5 and 6 months) explored the source of the discrepancy, for example, they systematically tested their hands for numbness (Bower et al., 1970b).

These results have been difficult to obtain in other laboratories. J. Field (1977) used a mirror device to present an intangible visible object to 3-, 5-, and 7-month-old infants. The infants were attentive to the visible object and inclined to reach for it, but they showed no surprise or distress when their hands encountered empty space. Yonas and his colleagues (see Yonas, 1979) investigated developmental changes in reactions to an intangible visible object, again using a stereoscopic shadow-casting device. They found no evidence for surprise and no discernible tendency to test the hands for numbness in infants as old as 9½ months. Thus, young infants may show no discernible reaction to this discrepancy, whereas older infants may systematically explore the object with their hands but show no surprise or distress.

In further studies of visual-haptic perception, objects were presented through a mirror device so that one object could be felt at the location at which a second object was seen. Two kinds of visual-haptic conflict are introduced with this device. First, as the infant reaches for an object at its visible location, his hand does not come into view. Second, the object that the infant contacts manually can be made to differ in size, shape, texture, or substance from the object that he sees. Lasky (1977) investigated 2½- to 6½-month-old infants' reactions to reaching for an object with or without sight of the hand. Failure to see the hand reduced the reaching of 5½-month-olds, but not of younger infants. The frequency of reaching at younger ages was very low in both conditions, however. E. W. Bushnell (1979, 1980) investigated infants' reactions to touching an object with different properties from the object they saw. When infants reached for a visible object, they encountered an object of a different shape and texture. In a control condition, infants encountered an object with the same properties as the visible object. Infants were videotaped and their facial and manual reactions were observed. Infants of 8 months reacted equally in the two conditions. Infants of 9½ and 11 months, however, were more inclined to explore visually and manually in the discrepant condition.

These findings present a puzzle. Because young infants are sensitive to relationships between the visible and tactual substance of an object felt in the mouth (Gibson & Walker, 1982) and because they reach for visible objects that are nearby and graspable (Bruner & Koslowski, 1972), why are they not surprised when a visible object turns out to be intangible? There would seem to be four possible explanations. First, haptic exploration has its own developmental course (see *Exploring and Attending*). Infants may not be sensitive to all of the properties of an object held in the hand until manual exploratory skills increase. Exploration by the mouth, in contrast, appears to mature very early. Second, young infants may not respond emotionally to events in ways that adults can interpret. Expressions of surprise, fear, or distress may themselves develop (Sroufe & Waters, 1976). Third, infants may be subject to capture effects, as are adults (Welch & Warren, 1980). Visual information for an object of one shape may modify the infant's haptic perception of that shape so as to eliminate any perceived discrepancy. Fourth, young infants may be able to use their perceptual capacities only in limited ways. In Rozin's (1976) terms, young infants may have only limited access to the information that their perceptual systems provide. For example, an infant may be able to register the relationship between visual and haptic information for the shape of an object, and this capacity may guide reaching for a visible object or looking at an object that has been felt. But when there is a discrepancy between the information detected by the eye and hand, the discrepancy that is registered may not serve to guide a search for the source of the discrepancy and may not elicit emotional communications. The accessibility hypothesis proposes that developmental acquisitions are rooted in innate structures that have evolved for quite specific purposes. But developmental changes of considerable importance will occur as these mechanisms come to function in new ways.

Perceiving Another Person: An Example

We close this section on object perception by focusing on the development of the perception of people. Within the first six months, infants become sensitive enough to the properties of the face to discriminate one face from another in pictures, in three-dimensional representations, and in live presentations. For example, Fagan (1972) familiarized infants with a photograph of one face and then paired that photograph with one of a different face for a preference test. Infants of 5½ months exhibited a preference for the face they had not seen, whereas 4-month-olds exhibited no reliable preference. The negative results with 4-month-olds may, however, be attributable to the techniques Fagan used—infants as young as 3 months have been found to discriminate between photographs of two different faces in studies using a habituation technique (Barrera & Maurer, 1981; Maurer & Heroux, 1980). There appears to be no reliable evidence that infants can discriminate between photographs of two different faces below 3 months, even if one photograph portrays the infant's own mother (G. Olson, 1981).

These studies show that infants are sensitive to some property or relationship that distinguishes a photograph of one face from a photograph of another face, but they do not indicate what relationships infants perceive. To address the latter question, investigators have studied infants' reactions to schematic faces. With these displays, specific features and feature combinations can be varied systematically, and infants' responses to these variations can be assessed. This literature has been reviewed in detail by Sherrod (1981). We mention only a few findings. Two-month-old infants have been shown to discriminate normally arranged faces from a variety of bizarre arrangements when tested with a visual-preference procedure (Fantz, 1966) or a habituation procedure (Maurer & Barrera, 1981). This discrimination has also been reported with newborn infants, in a study using a visual tracking procedure (Goren, Sarty, & Wu, 1975). Older infants have been shown to respond to changes in particular features of schematic faces. For example, Caron, Caron, Caldwell, and Weiss (1973) presented infants of 4 and 5 months with one schematic face for habituation, followed by a second test face. The test stimulus was always a regular schematic face; the habituation stimulus was the same face with one or several features missing or misplaced. The youngest infants were most sensitive to changes in large external features of the face, such as the hair. Changes in the eyes were noticed next, and changes in the nose and mouth were noticed last, at 5 months.

These studies and many others (see E. J. Gibson, 1969) suggest a rapid development of face perception in infancy. But even these studies may underestimate the young infant's perceptual competence, because they all presented infants with static representations. Natural faces are active and constantly changing in expression. The face undergoes deformations in which different surfaces move relative to each other and some surfaces are stretched or wrinkled.

One experiment presented 4- and 5½-month-old infants with films of the head and shoulders of an unfamiliar woman (Spelke, 1975). During a habituation phase, the person was seen to engage in six different repetitive actions, with different expressions, for 20 sec. each. The actions included smiling, nodding, yawning, and the like. In the test that followed, the same person or a different person—same age, sex, and coloring—engaged in two new actions, with new expressions. Infants of both ages looked longer to the new person during the test; habituation to presentation of a person performing several actions generalized to presentations of new actions by that person. Infants can perceive some continuity in events in which one person does different things. They may perceive that person to persist over changes in what she does.

Infants may be less able to perceive the identity of a person over different poses if that person is presented only in still photographs, but they eventually become able to do so. Fagan (1976) presented 7-month-old infants with a photograph of a single face presented in a frontal orientation. After familiarization, infants received a preference test with the same and a very different face, both presented at a different orientation, that is, a profile or a three-quarter view. Infants exhibited a novelty preference for the photograph of the person they had not previously seen. Thus, 7-month-old infants appear to recognize a face in two different photographs.

Fagan's (1976) experiment indicates that infants perceive some similarity between two different photographs of the same person. It suggests that they may recognize the person in the two views. But children continue to have some difficulty recognizing people in photographs and in very short filmed episodes until adolescence. They have trouble recognizing a person over changing facial expressions, hairstyles, and even accessories, provided that the comparison person is similar in appearance.

Carey and Diamond (1977) asked children of 6 to 10 years which of two photographs depicted the same person as an original inspection photograph. The two test pictures portrayed women of the same hair color. The correct person's hairstyle, clothing, and expression sometimes changed from the inspection to the test photograph. There was a gradual increase in accuracy with age, and a gradual decline in attention to accessories and other features extraneous to the face. Young children appeared especially apt to match faces by considering individual features such as the mouth; older children appeared to attend to the total configuration of facial features. The developing ability to perceive the distinctive configuration of a face appears to be tied, in part, to maturational changes occurring at the time of puberty (Carey, 1978). Marked improvements with age in face perception were also reported by Dirks (1976) who showed preschool and school-aged children short videotapes of unfamiliar people performing different actions. It is interesting that children perform better at this task if they are allowed to see more than one view of a person. The identity of a person appears to be perceived better if the person performs varied or extended actions.

Infants not only perceive the identity of a person over changes in his actions and expressions; they also appear to discriminate some actions and expressions. The most dramatic evidence for perception of another person's actions comes from studies of imitation. Newborn infants have been reported to imitate some of the actions of an adult (Church, 1970; Dunkeld, 1978; Maratos, 1973; Meltzoff & Moore, 1977, 1979; Trevarthen, 1977). They seem particularly apt to imitate gestures of the mouth, such as tongue protrusion (Church, 1970; Meltzoff & Moore, 1977, 1979). Early imitation has not been found by all investigators (Hamm, Russell, & Koepke, 1979; Hayes & Watson, 1979), and some of the studies reporting imitation have been criticized (see Meltzoff & Moore [1977] for a critique of earlier studies; also see Anisfeld [1979], Masters [1979], and Meltzoff & Moore [1979]). If young infants do imitate actions of the face, they must have considerable ability to perceive faces and their actions. Note, however, that the young infant's ability to imitate an expression appears, even by the most generous estimate, to be quite limited. The ability to imitate actions outside of the child's normal repertoire, and to do so in a deliberate manner, develops slowly over the course of infancy and childhood (Aronfreed, 1968; Parton, 1976; Piaget, 1951).

The development of sensitivity to the expressive behavior of others has become a topic of considerable interest. This development seems to begin in infancy, although it continues through childhood. It is difficult to determine whether an infant responds to an emotional expression as such (Oster, 1981). Nevertheless, infants appear to discriminate among certain expressions of emotions, particularly if one expressed emotion is joy and the other is anger, sorrow, or surprise (Barrera, 1981; Kreutzer & Charlesworth, 1973; LaBarbera, Izard, Vietze, & Parisi, 1976; Walker, 1982; Young-Brown, Rosenfeld, & Horowitz, 1977).

Research by Walker (1982) suggests that infants perceive and react to the affordances of an expressive face in at least a rudimentary way. Infants were videotaped as they watched a film of a happy or sad face. Experimentally blind but experienced observers using a forced-choice procedure judged better than chance what film a baby watched by looking at her facial expression alone. Walker's observers were unable to describe explicitly the basis of their judgments.

There are developmental changes in the child's sensitivity to the emotional expression of a face, particularly when he views the face only in a photograph. The development of sensitivity to facial expressions has been studied in diverse ways. For example, children have been asked to label the emotion expressed in a picture or to choose the pictured face whose expression is most appropriate in some given context. Findings vary across tasks, but, in general, there appears to be a steady increase in sensitivity to expression over the childhood years (Oster & Ekman, 1978). As in the infant studies, children seem most sensitive to expressions of joy. They are least able to identify fear in pictures. Other emotions show no consistent ordering of difficulty (Oster & Ekman, 1978).

In nature, faces do not come alone. A child encounters people with characteristic voices, movements, actions, and odors. Recent studies have focused on the infant's sensitivity to one of these relationships, that between the voice and the visible movements of a speaking person.

When a person speaks, his face moves in synchrony with his speech. Adults are sensitive to the synchrony and are disturbed when it is disrupted, as in poorly dubbed movies. As we have already noted, infants 12 to 16 weeks old are sensitive to this synchrony as well (Dodd, 1979; Spelke & Cortelyou, 1981). By 8 months, infants also respond to relationships between auditory and visual information about the sex of a person. Presented with photographs of a man and a woman's face while one man or woman's voice is played between them, infants tend to look preferentially to the face of the person whose sex matches the voice (Miller & Horowitz, 1980). Finally, Walker (1982) showed that infants of 5 and 7 months can coordinate auditory and visual information about the emotional expression of a person (see *Obtaining Information About Events*). Young infants perceive innately, or learn rapidly, about many of the properties of a face both optically and acoustically specified.

The preceding studies suggest that infants perceive people as meaningful objects. They do not discriminate and recognize people, their expressions, and their actions as meaningless patterns. Infants perceive and respond to the affordances of a person as an object that can move, gesture, and engage the infant in reciprocal interactions. Perceptual development seems to involve not the imposition of a constructed meaning on a meaningless pattern, but the discovery of new affordances of objects that are already perceived as meaningful.

OBTAINING INFORMATION ABOUT PLACES

The environmental layout consists of surfaces—surfaces that meet, surfaces that are nested within other interlocking surfaces, and surfaces that extend indefinitely into the distance. Where surfaces end or turn abruptly, there are edges; where they break, there are apertures; where they meet, there are corners; and beyond the edges of any surface are vistas through which a layout of more distant surfaces can be seen. This layout of surfaces has affordances for behavior. Most flat, rigid, extended surfaces afford support and locomotion. Apertures and tunnels afford passage to a locomoting animal, whereas upright surfaces placed in his path are obstacles that prevent locomotion or afford collision. To an adult, the surface layout is perceived to extend beyond the immediate field of view, and the properties and affordances of the layout are perceived as constant over changes in the point of observation. Thus, the environmental layout can serve as a reference system within which a perceiver can locate himself in relation to other objects and objects in relation to each other.

The development of perception and knowledge of the spatial layout has occasioned debate on many topics. Philosophers and psychologists have pondered the origins of space perception and the role experience plays in its development, the nature of the child's knowledge of spatial relationships and the proper mathematical description of spatial knowledge. We will examine these and other issues in the course of this discussion. Our focus is not, however, on perception of space as such, but on perception of the environment.

Two Views

According to one class of theories, perceptual knowledge of space is a construction, a system of inferences based on the child's action. Theorists as different as Berkeley and Piaget have proposed that the child comes gradually to appreciate the spatial properties of things as she acts on the world and as activities of the hand and body endow her visual sensations with three-dimensionality. According to Piaget (1954), knowledge of space begins to develop over the infancy period. Near space is constructed before far space, because the child's range of effective actions broadens only gradually. Moreover, the child constructs space in relation to herself before she constructs an objective spatial layout. As the child gains the capacity for symbolic thought, her knowledge of space gradually becomes objective and comes to bear the formal properties of progressively higher geometries.

In contrast to these views is the theory that the environmental layout is specified by invariants in the optic array and that perceivers detect the layout as they move about. Space need not be inferred from action. Instead, properties of the spatial layout can be detected by mechanisms that are attuned to the appropriate stimulus invariants (J. J. Gibson, 1966, 1979). J. J. Gibson spent much of his life attempting to describe the invariants underlying perception of that layout, and his work has led to a number of discoveries and suggestions.

A developmental theory based on J. J. Gibson's analysis (see E. J. Gibson, 1969, 1982) has proposed that mechanisms for detecting invariants specifying properties of the spatial layout develop very early. The child uses perceived properties of the layout as relational information for the positions, orientations, and movements of objects, including the self. This analysis emphasizes the role of events, often brought about by the observer himself, in specifying surfaces. Extended surfaces are best found out about by looking or moving around. Walking toward a wall provides evidence at once—by the optical expansion pattern produced—of its orientation relative to the observer. And exploring the larger spatial layout—the layout of one's house or school or town—can only be accomplished through locomotion. Perception and locomotion are reciprocal, for walking around is itself guided by visual information about the layout of surfaces.

Visual Proprioception

Adults rely heavily on visual information about their own movements and posture when they stand and locomote. If all the elements of the optic array begin to flow outward from a single point, we perceive ourselves to be moving in the direction of the focus of expansion (J. J. Gibson, 1966; Warren, 1976). If the array begins to rotate to the right, we soon feel ourselves spinning to the left, even in some cases to the point of nausea. If the array is tilted to an oblique angle, we feel ourselves tilting the opposite way (Witkin, Lewis, Hertzman, Machover, Meissner, & Wapner, 1954). If surfaces in the environment suddenly swing from their normal orientation to a forward tilted orientation, we feel ourselves falling forward and may falsely compensate for this movement so far that we lose our balance (Lishman & Lee, 1975). All these phenomena reflect the adult's perception of the layout as permanent and immoveable, and of himself as a moveable object within it. Moreover, these phenomena testify to the adult's perception of the invariant relation between his own upright posture and the orientation of the walls and the ground.

A constructivist theory of development should predict that the effect of vision on proprioception will grow with age, but in fact, the effect diminishes. Subjects aged 8 years to adult have been placed in a tiltable chair in a tilted room and asked to adjust the chair until it was upright. Subjects of all ages were influenced by the orientation of the room, and this influence was greatest at the youngest ages (Witkin et al., 1954).

In other studies, even infants have been shown to use visual information as a guide for posture control. Lee and Aronson (1974) placed 11-month-old infants who had recently learned to stand in a room whose walls could be made to swing toward and away from them. The infant stood on the ground in front of the mother; both the mother and the floor remained stationary as the walls moved. The effects were even more dramatic than with adults. When the room was swung toward them, infants evidently perceived themselves to be falling toward the wall, for they leaned sharply backward and lost their balance. The opposite pattern was obtained when the room was swung away from them. Despite the presence of the mother, the stationary ground, and vestibular information that the child was upright and unmoving, infants evidently felt themselves to move and the walls to stand still in response to the discordant visual flow pattern. Infants evidently use visual information about the extended surfaces in the environment to guide locomotion. The absence of this posture-control system in blind infants may partly explain their considerable delay in onset of locomotion.

Lee and Aronson's infants were beginning to walk. It is conceivable that they learned about the correlation of optical motions and posture changes during a fall. Such learning is less likely to explain the results of studies by Butterworth (Butterworth & Cicchetti, 1978; Butterworth & Hicks, 1977; for a review, see Butterworth, 1981). Butterworth and Hicks (1977) observed the reactions of infants of 10 and 16 months who were seated in a swinging room. The older infants were capable of standing; the younger infants were not. Infants of both ages reacted to the visually specified information for movement. In fact, further research suggested that younger infants in a seated position are more responsive to this information than older infants (Butterworth & Cicchetti, 1978). Finally, infants of only 2 months made appropriate postural adjustments of the head to compensate for a swinging room (Pope, cited in Butterworth, 1981). Because these infants had never stood or walked on their own, it is unlikely that they had learned to correlate visual information with posture control. Infants may have unlearned visuomotor programs that use optical motions to guide postural adjustments.

Perceiving Affordances of the Layout

Obstacles

When a perceiver faces a wall or an obstacle and walks directly toward it, a projection of the obstacle expands symmetrically in the field of view, its contours moving at a geometrically increasing rate. As the moment of impact approaches, the obstacle comes rapidly to fill the field of view. This explosive pattern of expansion is called looming, and it specifies imminent collision. Adults detect this flow pattern and use it to guide locomotion and avoid running into things. Once infants can walk, they too avoid walking into walls and other surfaces. Do toddlers learn to avoid obstacles by trial and error, or are they innately sensitive to information for impending collision? These questions are addressed by studies in which an obstacle is brought toward an infant who is much too young to locomote, and the infant's reactions are observed.

Schiff (1965) originally observed responses to looming optical displays in a variety of newborn animals. Animals were presented with a screen projection of an object that was produced by a shadow-casting device. The projection was made to expand in a looming pattern. Monkeys, kittens, and crabs all backed away from the looming display, but not from a display in which an object appeared to recede. The same response was observed with a variety of objects. Schiff concluded that these animals perceived an impending collision with the object and acted to avoid it.

Observations of human infants initially supported the same conclusion. Bower, Broughton, and Moore (1971b) presented 2-week-old infants with a real object that approached them or receded. Infants were reported to widen their eyes, withdraw their heads, and interpose their hands between their faces and the object as the object reached the near point of approach. When the object was replaced by a shadow pattern presenting the same expansion pattern without other information for depth, the response was still observed, although it was reduced. When air displacement from an approaching object was presented with no accompanying visual information, no defensive response was obtained. Bower et al. (1971b) concluded that the infants were sensitive to visual information for the approach of an object. Optical expansion patterns seemed to provide part of this information, although other optical information might contribute as well, such as information for distance.

Ball and Tronick (1971) compared infants' responses to approaching objects and expanding shadow patterns when the optical expansion was symmetrical (specifying that the object was moving toward a collision with the infant) or asymmetrical (specifying that the object would pass by the infant with no collision). Infants reacted differently to these events. When the object pattern expanded asymmetrically (on a miss course) infants followed the expanding pattern with interest, exhibiting no avoidant behavior. It was concluded that infants perceive the approach of an object and its affordance for collision.

This conclusion has been questioned, because infants under 8 months exhibit no discernible fear of a looming object as they withdraw from it (Cicchetti & Sroufe, 1978). Perhaps, then, the defensive reaction has been misinterpreted. Yonas, Bechtold, Frankel, Gordon, McRoberts, Norcia, & Sternfels (1977) proposed that behavior labeled defensive is really exploratory, that is, infants may attempt to maintain visual fixation on the rising contour of a shadow pattern, retracting the head in order to do so. Yonas et al. (1977) discovered that patterns that do not specify collision will also elicit head withdrawal under certain conditions, provided that the upper contour rises.

Despite these considerations, it now seems clear that very young infants do show avoidant behavior when given visual information for the approach of an object (see Ball & Vurpillot, 1976; Pettersen, Yonas, & Fisch, 1980; Yonas, Pettersen, & Lockman, 1979; Yonas, Pettersen, Lockman, & Eisenberg, 1980). Bower reported that infants will show appropriate reactions to an impending collision with an object whose contour does not rise (Bower, 1979; Dunkeld & Bower, 1980). Infants of 2 to 4 weeks were presented with the shadow of a rectangle undergoing continuous perspective transformations, specifying rotation about a horizontal axis. As the upper contour neared its lowest position, the object appeared about to fall on the infants. At that point, the infants backed away.

Finally, Carroll & Gibson (1981) investigated 3-month-old infants' reactions to two patterns of symmetrical expansion with very different affordances. One display consisted of a patterned panel against a patterned background. The panel approached the infant on a hit path. In the other condition, the display that approached the infant was an identically shaped aperture in a larger panel through which a stationary rear surface with the same pattern could be seen. Infants responded to the approach of the obstacle in the characteristic way, withdrawing their heads and extending their arms toward the object. The response to the aperture was very different. Infants initially tracked the rising contour, but then they turned to one side to track an edge of the surface as it moved close. Measures of changing head pressure differentiated the two events. This study indicates that avoidant behaviors are not elicited by an expanding contour as such. Instead, an approaching surface has affordances for the infant, and the affordances depend on whether it is an obstacle or an aperture. Patterns of occlusion and disocclusion serve to distinguish these affordances. If an obstacle approaches, more and more of the background surface becomes occluded. If an aperture approaches, more and more of the background surface becomes disoccluded. Young infants may perceive rigid surfaces, openings, and their affordances by detecting this information.

Surfaces of Support

When do infants first perceive that a solid, flat, rigid surface will support them and their locomotion? Studies of responses to a visual cliff indicate that this perceptual ability is innate in some animals. Gibson and Walk placed animals such as rats, chicks, and kids on a board from which they could descend onto either of two transparent surfaces (Gibson & Walk, 1960; Walk & Gibson, 1961). On the shallow side, there was a patterned surface directly beneath the glass; on the deep side, the patterned surface was several feet below. Newborn kids and chicks immediately descended to the shallow side, but all avoided the deep side, as did dark-reared rats. Human newborns could not be tested because they do not locomote independently, but infants were tested when they could crawl. The majority of them avoided the deep side of the cliff. It appeared that a flat, opaque rigid surface is perceived as affording support as soon as locomotion is possible. The development of perception of these affordances seemed not to depend on trial-and-error learning.

Other observations seem to challenge this conclusion. First, infants of many species show little fear of the deep side of the cliff. Although baby goats avoid the deep side of the cliff from birth, they do so with no signs of fear. Young human infants who are placed directly on the deep side of the cliff do not seem to be afraid either; their faces remain calm, they do not cry, and their heart rate does not accelerate (Campos, Langer, & Krowitz, 1970; Scarr & Salapatek, 1970). Second, not all human infants avoid the deep side of the cliff in any experiment. Third, young prelocomotor infants who have learned to locomote with the aid of a walker show no avoidance of the deep side of the cliff, they will cross in the walker to either side with equal readiness (Rader, Bausano, & Richards, 1980; see also Scarr & Salapatek, 1970). Older infants who refuse to crawl onto the deep side will also cross to that side if placed in a walker (Rader et al., 1980).

These findings have prompted reinterpretations of the development of avoidance of the deep side of the visual cliff. Campos, Hiatt, Ramsay, Henderson, & Svejda (1978) proposed that, for humans, experience plays a role in the development of perception of a dropoff and its consequences. Children learn—perhaps by trial and error—that visually specified dropoffs do not afford support and should be avoided. Rader and her colleagues (Rader, et al., 1980; Richards & Rader, 1981) presented evidence against this interpretation. In several studies, they examined the development of cliff avoidance in babies that varied in age, amount of crawling experience, and age of onset of crawling. If infants learn to avoid the deep side, then those who are older or more experienced crawlers should show greater avoidance. This did not occur. The only reliable predictor of cliff avoidance was age of onset of crawling. Babies who began to crawl at an early age (before 6½ months) showed little avoidance of the cliff, regardless of when they were tested. Babies who began to crawl at a later age showed a strong tendency to avoid the deep side.

Rader et al. (1980) proposed that cliff avoidance depends on a visuomotor program that matures at about the time that crawling begins. The visuomotor program leads infants to shift their weight forward—the first step in crawling—only when they detect visual information for a supporting surface. Rader et al. proposed that this program depends on no specific experience for its development. For infants who are late crawlers, the program will have matured by the time crawling begins, and thus late crawlers will avoid the deep side of the cliff. But infants who begin crawling before the program matures must use nonvisual information for a supporting surface—probably tactile information—to guide their locomotion. For these infants, crawling may continue to be guided by tactual information. Because the deep side of the cliff feels safe, early crawlers will not avoid it.

In summary, infants seem able to perceive, without specific experience, that obstacles afford collision and that rigid, flat opaque surfaces afford support. Nevertheless, these abilities are very restricted in expression. Young infants withdraw from an object on a collision course, but they are not distressed by an impending collision. Most infants avoid crawling onto a cliff as soon as they are able to crawl, but they show no fear of the cliff until months later and may cross over the cliff if placed in a walker. For a young infant, information about an impending collision or a dropoff may not be accessible to systems for communicating a state of personal danger to others (such as expressions of fear) or to actions that are not species-specific adaptive responses to an impending collision or a dropoff (such as maneuvering a walker). As we grow, the affordances we perceive may come to guide a greater and greater repertoire of behavior.

Paths for Locomotion

There is more to perceiving the layout than perceiving obstacles, openings, and supporting surfaces. Most environmental layouts consist of an arrangement of surfaces that form potential supports, obstacles, passages, and vistas. A perceiver must plot a course through this layout, getting from where he is to where he wants to go without hitting obstacles or running into blind alleys. Furthermore, there are usually many potential paths through a layout, and it is desirable to choose the most efficient one.

The development in children of the ability to navigate through a cluttered environment has received very little study. Lockman (1980) conducted a longitudinal study with infants aged 8 to 12 months. Infants were presented with a desirable toy that was then moved behind an opaque or transparent barrier. In some conditions, the infants had to crawl around the barrier. In other conditions, they could obtain the toy by reaching around the barrier. In addition, infants were given an object-permanence task in which they had to retrieve an object that had been placed under a cloth. All the infants succeeded at this object-permanence task before succeeding at the barrier task. The ability to navigate around barriers evidently requires more than a capacity to search for things that are out of view. Among the detour conditions, the reaching tasks were solved at a younger age than the crawling tasks and the tasks with opaque barriers were solved earlier than the tasks with transparent barriers. Confronted with a transparent barrier, many of the younger infants attempted to reach through the barrier and abandoned all attempts to obtain the object when that procedure failed.

Knowledge of Larger Layouts

As children begin to locomote, they come to navigate over a larger and larger terrain. A young child must not only plot a course across a room, avoiding obstacles, but also get from the kitchen to the dining room, from the living room to the bedroom, from the front door to the backyard. These courses involve routes and goals that are not visible to the child as she begins her journey. She must use knowledge of the layout to direct her locomotion. What do children know about the layout of familiar environments like their homes, their schools, and their neighborhoods?

Children's knowledge of a familiar environment—a classroom or a school library—has been studied by H. L. Pick, Jr., and his colleagues with preschoolers (H. L. Pick, Jr., 1972) and with children in the first and fifth grades (Hardwick, McIntyre, & Pick, 1976). In these studies, children were asked to indicate where objects were without looking at them. They stood behind screens in different corners of the room and aimed a sighting tube at the objects. Preschoolers were as consistent as adults when they pointed to the same object from different places, but the adults were more accurate. Accuracy increased from first grade to fifth grade, although not from fifth grade to adulthood. But the accuracy of young children was impressive. For example, the average error for sighting was 9.58° for first graders compared to 6.53° for adults. Children know a good deal about the spatial layout of their schools.

Young children also have rudimentary knowledge of the layout of their homes. In one experiment (Pick & Lockman, 1979), children living in two-story apartments were asked to aim a sighting tube at targets in other rooms of the apartment. Aiming accuracy improved with age, but it was high at all ages. For example, the average aiming error was 11.5° for adults and 27.1° for children aged 4 to 6. Accuracy was higher within a floor than across floors for all the children, particularly the youngest, although not for the adults. In a further study, 4- and 5-year-olds were able to identify rooms of their homes while standing outside, and they were able to construct a rudimentary map of the furniture in individual rooms in the house (Pick, Acredolo, & Gronseth, 1973).

Finally, Cohen, Baldwin, and Sherman (1978) investigated children's knowledge of a familiar, larger scale environment. Children of 9 and 10 years were asked to estimate distances between places at their summer camp. Children's estimates of distance were systematically related to the true, euclidean distances between points. However, both children and adults overestimated distances that were difficult to travel between relative to distances that were easily traveled. Kosslyn, Pick, & Fariello (1974; see also Anooshian & Wilson, 1977) familiarized preschool children and adults with an artificial environment containing objects and barriers. Barriers could be opaque or transparent. The subjects were then asked to estimate distances between pairs of objects. The adults overestimated the distance between two objects only if an opaque barrier separated them. Children overestimated that distance if either an opaque or a transparent barrier separated them. Nevertheless, children's and adults' estimates were related to euclidean distances.

Most of these studies suggest that children's knowledge of space is somehow affected by their locomotion. Thus, Pick & Lockman (1979) found that children know more about spatial relationships between rooms on the same floor, which they can walk between with ease, than they do about rooms on different floors, which are separated by stairways. And Cohen et al. (1978) and Kosslyn et al. (1974) found that children overestimate distances between two points if the route one must travel between them is longer. It is not surprising that locomotion should play a role in the child's spatial knowledge for it is only by locomoting that one can obtain the sequence of vistas that provides information about the larger environmental layout. But what is most striking about these experiments is how limited the effects of locomotion are. Children and adults overestimate distances between points separated by a barrier, but their distance estimate is not nearly as great as is the length of the path that would be needed to circumvent the obstacle. Children are more accurate at judging the direction of an object in a different room if that room is more easily walked to, but their estimates reflect the true direction of the object, not the direction in which they would need to walk to get to the object. Thus, children are able to gain spatial knowledge that goes beyond the paths they have taken.

In light of these findings, one might expect that children, who are introduced to a new environment and are taken through that environment along some set of paths, would gain knowledge of the spatial layout of that environment and so generate new paths they have never taken. That rats can sometimes do this is well known (Maier, 1929; Olton, 1977; Tolman, 1948). Nevertheless, some research suggests that young children have trouble charting new routes through familiar environments (Hazen, Lochman & Pick, 1978; Maier, 1936). Hazen et al. (1978) introduced children aged 3 to 6 years to a novel environment consisting of three rooms, each with four doors and each containing a toy animal. The children were taken along one route through the rooms repeatedly until they were able, on entering a room, to choose the correct door leading out to the next room and to report the animal they would encounter there. After training, the children were able to travel the familiar route in reverse with high accuracy. They were also able to anticipate the animals they would encounter as they traveled the route in reverse, although 3-year-olds made more errors than the older children on this task. Performance was poor, however, especially at the younger ages, when children were asked what animals lay behind doors they had *not* traveled through. Young children apparently did not perceive the layout of the rooms as a single unified place.

In experiments with simpler environments, however, very young children have been shown to be capable of finding new routes through a layout. Hazen (1979) taught children one route through three rooms. Then, a door normally traveled along the route was blocked, and the children were asked to choose another door. The 3-year-olds usually chose a door that led efficiently to the goal. Moreover, even a congenitally blind 2½-year-old child, and sighted, blindfolded children of that age, have been observed to find new, direct paths between objects (Landau, Gleitman, & Spelke, 1981). The children were placed in an unfamiliar room and taken from one object (*A*) to each of two others (*B* and *C*). When they were then asked to travel between *B* and *C*, they did so directly without returning to *A*. During their travels along the two training paths, the children evidently came to know the spatial relationships among all three objects.

As children grow, they come to use maps to find their way in a new place. We do not describe studies of map-reading and map-drawing here (see, e.g., Bluestein & Acredolo, 1979; Herman, Allen, & Kirasic, 1979; Siegel, Herman, Allen, & Kirasic, 1979; Siegel & White, 1975; Tonkonogaya, 1961; see also Mandler, Vol. III, Chap. 7). Suffice it to say that the development of map-reading seems to build on a prior ability, the gaining and using of knowledge of spatial layouts that children explore directly by locomotion.

Locating Moveable Objects

The environmental layout provides information about the spatial locations of objects. With development, children become increasingly adept at using this information to locate objects, especially objects that are out of sight.

There is a voluminous literature on the early development of search for hidden objects, research that springs from Piaget's theory of the development of the object concept (Piaget, 1954). That theory is only tangentially relevant to our present concerns and is reviewed elsewhere in these volumes (see *Mandler, vol. III, chap. 7; Harris, vol. II, chap. 9*). Infants below 8 months will rarely, if ever, search for an object that is fully out of view. Once infants begin to search for hidden objects, they do not always confine their search to the last place in which they saw an object disappear. If the object is displaced while it is out of view—for example, if it is hidden in someone's hand and then dropped into a box—children under 18 months may be completely baffled.

By the end of the second year, children can not only find an object that has just been hidden but can also find an object after a delay. DeLoache (1979) observed mothers playing an object-hiding game with children from 18 to 30 months of age. As the child watched, the mother hid a small toy somewhere in the home, for example, in a drawer or under a pillow. The child had to wait for 1, 3, or 5 min. and then find the object. Children found the object directly—with no errors—on the great majority of the trials. There was some developmental improvement, but even the youngest children found the object without error on 67% of the trials. In a second study, three objects were hidden on each trial. After a delay of 3 or 5 min., the children were asked to find one specific object, and they did so with high accuracy. Young children are surprisingly good at noting and remembering the locations of hidden objects.

In DeLoache's studies (1979), children had observed the objects as they were hidden. Many of the times that we search for things, however, we do not know where they are. We may forget where we left something or we may have dropped it inadvertently. In such situations, adults are usually able to search for the missing object systematically, narrowing down its possible locations and checking these one by one. As described earlier in our discussion of *Exploring and Attending*, search for objects becomes increasingly systematic over the course of early childhood (Drozdal & Flavell, 1975; Wellman et al., 1979). Children come increasingly to confine their search to a critical area—the only area in which the object could possibly be—and to search that area exhaustively.

To retrieve a hidden object, the child must mark its location in some way. Children have been thought to locate objects in terms of three frames of reference. First, they may locate an object relative to themselves, noting that a toy is hidden "on my right" or "above my head." This self-oriented, or "egocentric," reference system will serve the child well as long as she herself does not change position. Second, children may locate an object relative to some other object or objects, noting that a toy is hidden "under the sofa" or "behind the door." This landmark-oriented reference system will serve to locate the object as long as the landmark is unique (there must not be two identical sofas under which the object might be hidden) and does not move. Finally, the child may note the location of a hidden object relative to the larger, permanent spatial layout—the sky, the horizon, the walls of a room, or the perimeters of a piece of land. Because the layout as a whole never changes, the object's location can be retained indefinitely in a layout-oriented reference system, no matter how the child or other objects happen to move.

There have been many recent studies of the development of the use of these reference systems (for a review, see Pick, Yonas, & Rieser, 1978). Acredolo (1976) investigated children's use of the three frames of reference to locate a place in a room. In one study, 3- and 4-year-old children were introduced into an unfamiliar room with one door and one window, containing only a table to the right of the entry point. The child was taken to the table, was blindfolded, and was walked around the room until he lost his bearings. During this time, the table was discreetly moved. Then the child was led to a new place in the room, the blindfold was removed, and he was asked to find his initial starting point. A self-oriented reference system would dictate that the child move to the right, a landmark-oriented system would dictate that he move to the table, and a layout-oriented system would dictate that he move to the wall to the right of the door. There were two experimental conditions, one in which self-oriented and landmark-oriented systems were pitted against the layout-oriented system, and one in which self-oriented and layout-oriented systems were pitted against the landmark-oriented system. Children of both ages moved in a specific direction relative to the self.

In a follow-up experiment, these conditions were replicated in a smaller room with walls of different colors. In addition, a third condition was run in which the self-oriented system was pitted against the landmark- and layout-oriented systems. Each child was run in all these conditions. The 3-, 4-, and 10-year-old children showed no tendency to move in a particular direction relative to the self. At all ages, most children moved in a direction specified by the room itself. Those younger children who did not locate the object relative to the room tended to use the table rather than themselves as a reference point. Children may be less apt to locate objects relative to the self if they are in a room that is small, that has distinctive markings of its own (walls of different colors) or that is familiar.

In a further experiment, Acredolo (1977) trained 3-, 4-, and 5-year-old children to find a trinket under one of two cups on repeated trials. Then the children were taken to the opposite side of the room and asked to look for the trinket. If they located the trinket relative to their initial position, they should now move to the cup that had previously been empty. If they kept track of their own movements and located the cup relative to the layout, they should move in a new direction, to the old cup. Children were observed either in a room devoid of landmarks or in a room with tables or patterns on the wall that could serve as landmarks. Few of the children at any age used the self-oriented system. Use of this system declined with age and was lower, at all ages, when landmarks were present. Taken together, these studies suggest that even 3-year-old children are capable of locating an object relative to other objects and surfaces. They seem not to be bound to an egocentric reference system.

The use of a layout-oriented reference system at age 3 raises questions about its antecedents. Studies of infants and toddlers now suggest that even the youngest children can respond to the spatial position of an object relative to other objects and surfaces, although they only do so under restricted conditions. The tendency to locate objects relative to the self may be more prevalent in infancy than later in life.

Bremner and Bryant (1977) presented 9-month-old infants with a task resembling Piaget's (1954) object-search task. The infant faced two containers, one to his left and one to his right. After an object was hidden and retrieved five times in one container, the infant was moved to the other side of the table for five more search trials in which the object was placed under the same or a different container. Infants of this age sometimes tend to persist searching in the direction in which an object was formerly hidden, even if it is now hidden elsewhere. If infants do not take account of their own change of position, they should make more errors if the object is hidden under the original container (in a new egocentric direction) than if it is hidden under the other container (same egocentric direction). These errors occurred frequently, even when the color of the table could serve to mark the constant location of each box. However, in a follow-up study in which Bremner (1978b) used covers of distinctive colors, the number of egocentric errors declined. Infants showed some tendency to search under the cover with the color under which they had searched previously. Bremner concluded that 9-month-old infants can respond to the objective spatial position of an object; they are not inevitably egocentric. However, infants can only respond to an objective location in space if there are distinctive landmarks by which they can identify that location.

Similar findings have been obtained from research by Acredolo (1978), Acredolo and Evans (1980), and by Rieser (1979). Infants were trained to look to the left or right in anticipation of seeing a person, and then they were rotated to a new position. Infants tested in a room without landmarks tended to anticipate seeing the person in a particular direction relative to the self; those tested with distinctive landmarks tended to anticipate seeing the person in a particular direction relative to the landmarks. For example, Rieser's 6-month-old infants responded to the landmarks on 70% of the trials after a 90° rotation. Landmark-oriented search was particularly prevalent when infants were tested in their own homes (Acredolo, 1979).

By 18 months of age (and perhaps by 14 months), children can take account of changes in their own position and can perceive the constant location of an object even without landmarks. This ability has been demonstrated in ingenious studies by Heiman and Rieser (1980). Toddlers were trained to approach and touch one of eight identical windows arrayed in a circle. During training, the child always faced in the same direction—the target window was always straight ahead or to one side. After training, the child was rotated to face in a new direction, and then further testing began. Rather than turning in the trained egocentric direction, the toddlers spontaneously rotated themselves toward the true target. Most remarkably, they chose the shorter direction of rotation to get to the target. These children perceived a constant layout over changes in their motion without landmarks to guide them.

These studies suggest that children can localize objects relative to the self and to other things from a very early age. As children grow, they seem increasingly to rely on landmarks and distant surfaces as reference points. Nevertheless, we end this discussion with a caution. It is very difficult for any experimental study to provide conclusive evidence for or against the use of any reference system, because most spatial tasks can be performed in several different ways. Virtually all of the tasks in which a response is reinforced or a landmark is provided could be performed with no spatial reference at all.

For a child to use a self-oriented frame of reference, he must perceive or conceive of an object in space with a definite location relative to himself. An egocentric responder in the above studies need not do this. He may simply repeat a response that was successful in obtaining an object in the past. For example, consider an infant who has repeatedly seen a person through a window to his left and is rotated about the room so that a new window is to his left, opposite the original window. The infant may turn to the left in search of the person because he perceives that window to be the *place* where the person was seen before—this perception would reflect use of a self-oriented system. But alternatively, the child may turn to the left because he has been taught that leftward turning produces the person. The latter case involves no spatial reference at all.

A similar interpretation for landmark responding may be offered. To use a landmark-oriented spatial reference system is to perceive or conceive of an object in its spatial relationship to a second object. But children who respond to landmarks in the above studies need not do this. They might, alternatively, learn a nonspatial rule, such as "to see the woman, turn to the striped wall, wherever that is'' or ''to retrieve the object, lift the black cloth.'' The developmental progression from a preference for self-oriented searching to a preference for object-oriented searching may reflect not a developmental change in spatial reference systems but a change in a preferred response rule. Younger children may tend to persist in a given set of motor movements, whereas older children may tend to persist in responding to a particular object.

Because many tasks can be solved nonspatially, studies of spatial localization may underestimate the infant's spatial capacities. For example, training studies may actually encourage infants to rely on nonspatial task solutions, bypassing their knowledge of a spatial layout. Many studies have trained infants to act in a certain way to achieve a particular effect. The first time the infant responds, his action may be directed to a location in the layout. As the action is repeated, however, the infant may discover a contingency between his action and the event that it produces. We noted earlier that young infants actively search for such contingencies. Thus, an infant may adopt a simple response rule in these learning studies rather than relying on knowledge of the spatial layout. Such response learning has been reported to occur systematically in studies of spatial localization by children as old as 7 years (Lasky, Romano, & Wenters, 1980). But the fact that infants can discover contingencies between their actions and other events does not mean that they lack perceptual knowledge of spatial layouts.

Despite these problems, the studies by Acredolo (1977) and Heiman and Rieser (1980) indicated that preschool children can sometimes perceive the constant spatial positions of objects and surfaces as they themselves move. Further evidence for this conclusion comes from studies involving no training. Shantz and Watson (1970, 1971) allowed 3-, 4-, and 5-year-old children to walk through a room. As they did so, the room was rotated so that the direction of the walls relative to the child remained constant. Children of all ages were markedly surprised by this. They evidently expect changes in their own positions to be accompanied by changes in their spatial relationship to other objects and surfaces. Rieser, Doxsey, McCarrell, & Brooks (1980) gave toddlers an aerial view of a simple two-choice maze with the mother at its end and then allowed the children to crawl or walk to the mother when she called. Infants 25 months old tended to crawl in the correct (nonbarricaded) direction. Without any training, the 2-year-olds evidently coordinated information picked up in the aerial view (even a side view) with information available on the ground. A similar conclusion emerges from the studies, discussed above, of spatial localization in blind and blind-folded, sighted children (Landau et al, 1981).

Finally, Bremner (1978a) allowed infants to observe an object hidden repeatedly in one of two distinctively colored containers. Then the infants observed the hiding from the opposite side of the table so that the cup appeared in a new egocentric direction. Some of the children had searched for and retrieved the object during the initial familiarization, others had only watched the hiding and uncovering. Infants who had searched for the object previously tended to search perseveratively in the wrong location. Those who had only watched the hiding did not. Infants are, thus, capable of perceiving and responding to an object's new spatial location, and they are apt to use this ability when their task does not encourage them to rely on a well-rehearsed action.

Coordination of Perspectives

Children—even very young ones—seem able to perceive the properties of objects and places rather than the properties of their own perspective views. Yet, there are times when one must perceive properties of an array that are tied to one perspective. Most artists do this when they draw. And all perceivers need to take account of their own perspectives—and the perspectives of others—when they consider what they and others can and cannot see.

The ability to take account of the perspectives of other people appears to develop quite gradually over the course of early childhood. Young children have difficulty determining what a layout would look like from another's point of view, that is, what objects would be to the left, what to the right, what in front, and what behind. Three explanations for this difficulty have been offered. First, Piaget (Piaget & Inhelder, 1956) proposed that young children are egocentric: They cannot mentally adopt the perspectives of others. Thus, they are unable to appreciate that an array could look different to another person than it does to themselves. Second, it has been proposed that young children have difficulty transforming any mental representation of a scene. They cannot rotate a scene so as to imagine it from another point of view (e.g,, Huttenlocher & Presson, 1973, 1979). Third, it has been proposed that young children have difficulty with perspective-taking tasks because they cannot easily abstract *any* perspective view of an array, including their own (E. J. Gibson, 1977; a similar hypothesis has been advanced by Flavell, 1977). Young children's perception is focused on objects and events—on what things are—rather than on any one perspective view of those events. In perceiving objects and events, the child extracts information from a flow of stimulation over time as he moves his head and body and as objects and surfaces move. If events provide the normal information for perception, it may be difficult for a child to abstract the single frozen array that is captured by any one perspective view. With development, children become increasingly sensitive to these individual perspectives and their vicissitudes.

Piaget's position and the information processing alternatives are discussed elsewhere (see *Gelman & Baillargeon, vol. III, chap. 3; Mandler, vol. III, chap. 7*), so we will focus on the third theory. There is considerable evidence that children are not very sensitive to a single, frozen perspective on an array. As we have noted, children can judge the real size of objects with considerable accuracy, but they appear to be poor at estimating the projected size of an object. Even infants are more sensitive to real changes in an object than to changes in their own perspective view of the object (Bower, 1966; Day & McKenzie, 1973). Children also appear insensitive to the limits of what they can see in a single glance. Asked to draw an object, they typically draw more than can be seen from any single perspective (Freeman & Janikoun, 1972; Hagen & Jones, 1978; Sazont'yev, 1961). When asked to describe a scene, they describe what they know to be there, not what they actually ''see'' (Piaget & Inhelder, 1969). Finally, children of 3 to 7 years do not always seem to appreciate that two people occupying the same location will have the same view of a scene and that two people with different locations will see the array from a different perspective (Flavell, Omanson, & Latham, 1978), perhaps with a different degree of clarity (Flavell, Flavell, Green, & Wilcox, 1980).

If the young child perceives an object better than a particular perspective view, he might find it easier to determine if another person can see an object at all rather than to determine what the other person's perspective view of the object is. Recent evidence suggests that young children are quite good at determining what object and surfaces another person can see. (For a fuller discussion, see Flavell, 1977, and *Gelman & Baillargeon, vol. III, chap. 3*.) For example, if an adult asks a young child to show her a picture, the child will usually orient the picture so that the adult can see it (Lempers, Flavell, & Flavell, 1977). Even a blind child of 3½ has learned how to hold things so that an adult has an unobstructed view of them, taking account of the adult's line of sight and of any obstacles (Landau, 1981).

Most dramatically, infants are often able to detect which of several objects an adult is looking at. Infants as young as 4 months change their direction of gaze in response to the shifts of gaze of an adult with whom they are interacting (Scaife & Bruner, 1975). Butterworth & Cochran (1980) observed 12-month-old infants in face-to-face interaction with the mother. On signal, the mother broke off the interaction and looked to one of several visible objects. The infant's looking patterns were then observed. In the first experiment, four objects were present: some were in the infant's immediate field of view and some were not. When the mother turned to fixate a target, the infants watched her momentarily and then looked to an object as well, often pointing and looking back to the mother. Infants nearly always chose a target in the same lateral direction as the mother's glance, but they did not always choose the same target as the mother. When the mother fixated a target behind the baby, the infant usually chose a target within his own immediate visual field; he looked behind himself at the correct object only 25% of the time. When the mother fixated a target within the baby's visual field, however, the infant's accuracy rose to 85%. In a second experiment, 6-, 12-, and 18-month-old infants were presented with only one object at a time, either within or outside the immediate visual field. When the mother looked at the object, infants were likely to look at it as well, as long as both the object and the mother remained in the visual field. Infants would not follow the mother's gaze to an object if the object and mother could not be seen at the same time. Infants can determine what object another person is looking at, as long as they can view the person and the object at once.

Perceiving Geometric Relationships

This discussion of the child's perception of objects and surfaces in a spatial layout has so far bypassed a question of central interest: What are the spatial relationships among objects and surfaces that children perceive and know? This question has been raised most directly by Piaget (Piaget & Inhelder, 1956), who focused on the child's knowledge of topological, projective, and euclidean spatial properties. We follow Piaget's lead, discussing each of these sets of properties in turn.

Geometrical properties can be defined by the transformations that leave them invariant. Euclidean properties are those properties that are preserved over any rigid motions—rotations, reflections, and translations of points, lines, planes, or higher spaces. Most notably, distance and angle are invariant over any rigid motion, and so are all the geometric properties that can be derived from distance and angle. Projective properties are those properties of geometric objects that are invariant over any transformations that map one set of points into another set by projection from another point in space (of finite or infinite distance). These transformations usually change the distances between points and the angles formed by intersecting lines, but they preserve collinearity, the cross-ratio of four collinear points, and other properties that can be derived from these properties. Topological properties are those properties that are invariant over all continuous transformations that result in a one-to-one mapping of one set of points onto another set. Topological transformations generally do not preserve collinearity or the cross-ratio. They do preserve the connectivity of curves or surfaces, inside-outside relationships defined by a closed curve or surface, and incidence relationships such as the point of intersection of two curves. Topological, projective, and euclidean properties form a hierarchy: every geometric property that is invariant over all topological transformations will also be invariant over all projective transformations, and every property that is invariant over all projective transformations will also be invariant over all euclidean transformations. The converse statements are not true.[3]

What might it mean, then, for a child to have topological, projective, or euclidean knowledge of space? If a child had projective knowledge, he should be sensitive to all the properties of objects that are invariant under projection. This statement, in turn, implies two capacities. First, the child should be able to discriminate between any two objects that differ with respect to some projective property, such as a triangle and a square. Second, the child should perceive an equivalence between any two objects that are projectively equivalent, for example, any two triangles should be seen as somehow alike, since all triangles are identical under projection.

With this framework, we may consider which geometry or geometries best capture the child's spatial knowledge. Piaget and Inhelder (1956) and Laurendau and Pinard (1970) proposed that children progress from perceiving topological, to projective, to euclidean properties of space. This proposal has received little support. Cousins and Abravanel (1971) obtained similarity judgments of pairs within triads of cutout forms from 3½- to 5-year-old children. They found that the majority of judgments at all ages were based on euclidean features such as rectilinearity. Laurendau and Pinard (1970) obtained confusion errors from children, (2½, 3, 4, and 5 years of age) on an intermodal shape-matching task. They concluded from the pattern of errors that Piaget and Inhelder's (1956) theory was substantially correct. However, they reported that the youngest children tested could discriminate certain topologically identical objects as well as topologically distinct objects. Moreover, when their data were reanalyzed with a nonmetric multidimensional scaling procedure by Rieser and Edwards (1979), the solutions did not provide support for Piaget's theory. Younger children's confusions were based on relatively global properties, like angularity and curvilinearity; the older children's confusions were based on these plus more specific properties, like rectilinearity and jaggedness. All these properties, however, are euclidean. Moreover, Rieser and Edwards presented new data on the judgments of similarity of a parallelogram to 12 geometrical transformations of it. The judgments of 5-year-old children appeared to be based on projective and euclidean relations to an even greater degree than were the judgments of adults. Developmentally, there was evidence of differentiation of features, with similarity of euclidean properties easiest to detect. Recall that children's knowledge of the layout of an experimental space divided into quadrants and separated by transparent and opaque barriers was studied by Kosslyn et al. (1974). The subjects (preschool children and adults) judged distances between all pairs of objects located within the layout. Multidimensional scaling techniques applied to the data found that a euclidean solution described well the judgments of both children and adults, the children being remarkably accurate.

Recent evidence suggests that even infants are sensitive to euclidean spatial relationships. In a series of experiments, Schwartz and Day (1979) investigated discrimination by 8- to 17-week-old infants of simple two-dimensional figures. Infants viewed squares, rectangles, diamonds, or simple crosses. They were habituated to one figure and

then presented with one of several other figures for discrimination testing. The test figures could differ from the original figure in orientation, angular relationship within the figure, or both. Results were strikingly consistent across figures. Infants generalized habituated to the same figure at a novel orientation, but not to a figure composed of the same lines meeting at different angles from the original. Angle is a euclidean property unchanged by any rigid motion; orientation is changed by rigid motions. The fact that infants 2 and 3 months old discriminated changes in angle and generalized over changes in orientation suggests that they detected the euclidean properties. A recent study suggests that infants 6 weeks old, however, respond more to changes in orientation than to changes in angle (Younger & Cohen, 1982).

A child who is sensitive to euclidean spatial relationships, such as distance and angle, should be able to develop knowledge of a unified layout of objects at definite distances from each other and to use that knowledge to direct locomotion along new paths through that layout. We have already referred to evidence that young children have this ability (e.g., Hazen, 1979; Landau et al., 1981).

Overview

Infants and young children perceive surfaces as potential supports and obstacles, and they use visual information about these surfaces as a guide to the earliest locomotion. The information used by infants seems to be abstract and relational, obtained as the infant moves about. Infants use the perceived layout of surfaces as information about their own position and the positions and movements of other objects. They also have rudimentary abilities to take account of another perceiver's perspective. In all these cases, children seem to perceive the euclidean properties of the layout: the distances and angular relationships among points, edges, and surfaces in a scene.

Given these early abilities, it is not surprising that children gain spatial knowledge rapidly as they begin to walk. As children locomote, they encounter new vistas in which new aspects of the layout can be seen. Over this succession of views they gain knowledge of the layout as a whole. Their knowledge goes beyond the paths they have taken, for children perceive, from these paths, a unified layout of objects and surfaces.

There are developmental changes in the child's perception of the environmental layout. Older children live in a larger environment, of course, and they are more sensitive to its potential landmarks. They also know more about the particular tableau that a spatial array projects to an eye—their own or someone else's. And their perception of the layout and its affordances seems to become more and more accessible to action and thought. But there is no doubt that the spatial layout of the infant is a coherent, unified, three-dimensional place with affordances for action. The spatial layout does not seem to be constructed by the child through her action. It is perceived at a time when the child can act in only very limited ways, and perception guides action from the start. Moreover, the information for the layout used at an early age resides primarily in events that are produced as the infant moves about.

OBTAINING INFORMATION THROUGH PICTURES

Pictures and the Layout of the World

A picture consists of texture, shading, color, and form on a static, two-dimensional surface. It may represent an array of objects and surfaces, even events, but it is very different from any natural scene that it depicts. The amount of detail and the range of brightness in a real scene far exceed that in a picture. Moreover, a real scene contains objects and surfaces arranged in depth and objects that move; a picture never does. Perhaps above all, projections to the eye from a real scene change in regular ways as the observer moves. Near surfaces progressively occlude and disocclude far surfaces, and the visible points on all surfaces are displaced in directions and velocities determined by the three-dimensional distances and orientations of these surfaces. When an observer moves while looking at a picture, no occlusion and disocclusion is produced, and the motions of points on its surface specify the uniform, flat surface of the picture itself.

How, then, does a picture represent a natural layout of objects and surfaces? As J. J. Gibson (1950) has emphasized, there is information for the layout in a single frozen image, information produced by the gradients of texture of any surface in that scene. An observer may perceive depth in a picture by detecting those texture gradients. Appropriate texture gradient information will be available whenever a picture conforms to the laws of perspective. These laws are principles for projecting any real scene onto the plane of a picture from a single point of observation. They produce not only texture gradient information for depth but also linear perspective (convergence of objectively parallel lines with increasing depth) and size perspective (diminution of objectively equal-sized objects with increasing depth).

For an adult perceiver, then, a pictorial representation can be experienced in two ways. It can be seen as a plane surface, whose two-dimensionality is specified by motion perspective and other primary information for depth such as binocular disparity. And it can be seen as the scene that it represents, a scene whose three-dimensionality is specified by texture gradients and by linear and size perspective. Adults typically see a picture in both ways at once, that is, as a two-dimensional depiction of a three-dimensional layout.

How do children perceive the layout in pictures? According to one view of perceptual development, the static image is primary and should be the easiest configuration to perceive. According to the view guiding this chapter, invariance over change is primary and static perception is a special case. Young perceivers are attuned to invariant stimulus relationships that are produced as they move about. Perception of static forms in pictures should develop later than perception of objects and events. It remains possible, however, that infants are also sensitive to invariant information within a single glimpse, such as texture gradient information. If that were true, then infants might perceive a three-dimensional array in a picture if the two-dimensionality of the picture itself were deemphasized.

We begin our review by discussing the sensitivity of infants and children to information in static, two-dimensional, patterned surfaces. Then we discuss their perception of three-dimensional objects and scenes represented in pictures.

Perceiving Abstract Patterns

Volumes have been written on children's developing perception of structure and meaning in two-dimensional forms (see Salapatek, 1975; Vurpillot, 1976; also see *Salapatek & Banks, vol. II, chap. 1*). We will not review this literature but will discuss representative findings in a few substantive areas. In general, it seems that infants and young children are sensitive to certain patterns and structure in pictures but that they are much more sensitive to structure in the natural world.

Unity

The ability to perceive stable units in a picture—to perceive what goes with what—was described by the gestalt psychologists whose principles we have already encountered. Briefly, adults perceive relationships among elements in a picture united by the principles of proximity, similarity, good continuation, closure, and good form. (Common fate, a most important gestalt principle, depends on movement and so plays no role in pictorial perception.) We noted that infants show little sensitivity to these gestalt properties when they perceive objects (Spelke, 1982). We might expect, then, that infants will show little tendency to group parts of pictures together according to the gestalt principles. Research on infants largely supports this expectation.

Bower (1965, 1967) investigated the development of perceptual unity with infants in their first 2 months. He presented infants with patterns of dots or overlapping simple forms and then he moved the patterns in various ways. Adults organize these stationary patterns into groups in accordance with various gestalt principles. Bower sought to determine whether infants perceived the same organization by comparing their reactions to movements that preserved that organization with their reactions to movements that destroyed it. If infants grouped the patterns as adults do, they were expected to show surprise or increased attention to movements that broke up the units that adults perceive. Infants showed no surprise at the breakup of configurations whose unity followed from the gestalt principles of proximity, good continuation, and good form. Infants were surprised at the breakup of a pattern whose unity followed from the principle of common fate (Bower, 1965). Most likely, young infants are insensitive to the gestalt relationships that unite elements in a static picture.

A similar conclusion can be drawn from research by Salapatek (1975). Salapatek investigated 2-month-old infants' visual scanning of a matrix of identical forms containing a small region of different forms. For an adult, the gestalt principles of similarity, and possibly good continuation, immediately segregate this smaller region from the rest of the matrix. Adults and even 2-year-old children tended spontaneously to shift their direction of gaze toward that region. The infants did not. They did look at a region of distinct elements if it was brighter than the rest of the display, but not if it only differed in form. It seemed that the gestalt grouping principles did not define for infants a discontinuity in the matrix.

The results of these studies support those reviewed in our earlier discussion *Perceiving the Unity and Boundaries of an Object*. Infants are sensitive to the spatial arrangements and to the movements of surfaces, but they do not appear to perceive either objects or forms by detecting their static gestalt properties.

Forms

Although infants do not organize patterns into groups as do adults, they may, nevertheless, discriminate one pattern from another. Twenty years of research on pattern perception in infancy suggests that they do. This research is reviewed elsewhere (see *Salapatek & Banks, vol. II, chap. 1*). In brief, even newborn infants can discriminate between certain patterns, such as a bull's-eye and a checkerboard, under optimal conditions (Fantz, 1961). The basis of many of their discriminations seems to be the density of contour in a pattern (Karmel, 1969) or the curvature of individual contours (Fantz, Fagan, & Miranda, 1975).

Infants also perceive relational information in two-dimensional drawings. As noted in the section on the layout, Schwartz and Day (1979) studied the ability of 8- to 17-week-old infants to perceive very simple outline forms, such as angles, forked figures, and squares in various orientations. Angular relationships in such figures appeared to be perceived as invariant over rotation in the picture plane. Bornstein and his coworkers (Bornstein, Gross, & Wolf, 1978; Bornstein, Ferdinandsen, & Gross, 1981) investigated infants' perception of vertical symmetry in random patterns. Infants habituated more rapidly to symmetrical than to asymmetrical patterns, provided that the two halves of the pattern were suitably close together. Infants evidently detected the redundancy in vertically symmetrical patterns and perceived their structure more economically. By kindergarten age, and perhaps before, children are sensitive to horizontal symmetry (Boswell, 1976). Use of other kinds of redundancy in a pattern appears to emerge later in childhood (Chipman, 1977; Chipman & Mendelson, 1975).

One study suggests that young infants perceive a triangle as a coherent form. Milewski (1979) presented 3-month-old infants with a series of visual displays, each containing three dots in the shape of a triangle. In different displays, the sizes and positions of the dots (and, hence, the size of the triangle) varied, yet a triangle could always be seen by adults, with the three dots as vertices. Infants were presented with these displays, contingent on a suck of high amplitude. The presentations continued until their high-amplitude sucking habituated to a criterion level. Then infants were shown new displays of three dots forming a straight line. They dishabituated to this change in configuration.

Adults perceive contours in a two-dimensional array where no physical contour is given if other contours of the array follow certain constraints specifying an occluding surface. This tendency has traditionally been considered a demonstration of perceiving higher order relations (Kanizsa, 1976; see also Michotte et al., 1964, on amodal completion). Bertenthal, Campos, and Haith (1980), using the habituation method, found evidence of sensitivity to such contours in two-dimensional displays with 7-month-old but not 5-month-old infants.

Another difference between young and older infants has been found when the infant is presented with simple embedded patterns. Salapatek observed the scanning patterns of infants who viewed simple figures containing one embedded element (see Salapatek, 1975, for a general discussion). Infants under 2 months tended to scan only the external boundary of these figures; infants over 2 months scanned the internal boundary as well. Salapatek speculated that the younger infants were insensitive to the embedded form. Evidence consistent with this claim was provided by Milewski (1976), using a high-amplitude sucking procedure. Infants of 1 and 4 months sucked to bring to view one of Salapatek's (1975) embedded displays. After sucking had habituated, either the external or the internal figure in the display was changed in form, for example, a square embedded in a circle might change to a square embedded in a triangle or a triangle embedded in a circle. Infants of 4 months dishabituated to either change. Infants of 1 month dishabituated only to a change in the external figure. Sensitivity to embedded forms in a pictorial display appears to develop some time after 1 month.

Although young infants do not appear sensitive to an internal figure in a static display, they might be sensitive to internal regions of an object if those regions moved independently of the surrounding contour. I. W. R. Bushnell (1979) tested and confirmed this suggestion. He presented 1- and 3-month-old infants with an embedded form, such as those used by Milewski (1976) and Salapatek (1975), in a habituation-of-looking time procedure. In the first study, the display was stationary. As expected, 3-month-olds dishabituated to a change in the internal form, but 1-month-olds did not. In a second study, the internal form moved back and forth inside the stationary external form during both habituation and test. This movement had a marked effect on the younger infants' perception; they now dishabituated to a change in the internal element. A further experiment indicated that the movement of the internal element relative to the boundary was critical, not just the presence of movement per se. I. W. R. Bushnell (1979) concluded that young infants can perceive embedded forms in a display, but only if their movement segregates them from the rest of the display. Similar conclusions were reached by Girton (1979), who presented 5-week-old infants with eyes moving in a schematic face.

Perceiving Representations

Objects in Pictures

The ability to recognize an object in a picture appears to develop quite early. This has been demonstrated in studies of discrimination learning in which children are trained to respond differently to each of two objects or pictures and then are transferred to the opposite mode. For example, Steinberg (1974) trained children from 2 to 3 years old to discriminate among toy farm animals and then observed their transfer to pictures of the animals. Successful transfer was observed at 28 months, although not at 24 months. However, using a somewhat different procedure, Daehler, Perlmutter, and Myers (1976) obtained nearly perfect transfer from objects to pictures, and the reverse, at 2 years.

Most 2-year-olds have had considerable experience with pictures, playing games in which pictured objects are named. Yet, one study indicates that such experience is not necessary for the development of the ability to identify objects in pictures (Hochberg & Brooks, 1962), and more recent studies indicate that the ability to perceive certain objects in pictures is present at birth. Many of these studies involve pictures of faces, and have already been reviewed. For example, we have noted that newborn infants follow visually a picture of a regular face more than a scrambled face (Goren et al., 1975) and infants recognize the mother in a photograph by 3 months of age (Barrera & Maurer, 1981). Finally, infants of 5 months show some recognition of an unfamiliar person in a photograph. Dirks and Gibson (1977) presented infants of 5 months with a live, unfamiliar face for habituation. After looking time had declined, infants were shown photographs of the same face, one of different sex, skin color, and hairstyle, or one of the same sex, coloring, and hairstyle. Habituation generalized to the photograph of the same face and the similar one, but not to the one with very different features. These studies indicate that young infants can perceive some similarity between a face and a photograph of a face. As we already noted in the review of face perception, however, infants seem to be less sensitive to a face in a still photograph than to a face that is three-dimensional and animate.

Transfer from three-dimensional patterned arrays to photographs of them was demonstrated by Rose (1977) in 6-month-old infants. The patterns were simple designs, like a sunburst or an arrangement of four diamonds. Infants could visually differentiate a three-dimensional pattern from its representation and could also transfer responding from pictures to objects. DeLoache, Strauss, and Maynard (1979) investigated recognition of pictures of objects of varying degrees of fidelity to the object in infants of 5 months. Infants were familiarized with a real doll and given preference tests with the same doll and a new one or with photographs of the two dolls in color or in black and white. Infants showed a reliable preference for looking at the novel doll in all three conditions. In a second experiment, color photographs of two faces of women served as familiarization stimuli; black-and-white photographs and line drawings of the two faces as well as color photographs served as test stimuli. Infants tended to look longer at pictures of the novel person in all cases.

The Spatial Layout in Pictures

Can infants perceive a layout of objects in depth when given a static pictorial representation? It now appears that they can, as early as 6½ months of age, under certain restricted conditions. But infants and young children are less apt to perceive depth relationships in pictures than are older children and adults.

Yonas, Cleaves, and Petterson (1978) obtained evidence for pictorial depth perception through a study of reaching to a flat object whose spatial orientation was specified by perspective information. Infants were presented with a frontal trapezoid that was patterned so that it appeared (to adults) to be a slanted rectangular window (Ames, 1951). In one condition, infants viewed the window binocularly; thus, the frontal orientation of one window was specified by binocular disparity, whereas pictorial information suggested an oblique orientation. In the other condition, infants viewed the window monocularly; thus, less information for the true orientation was available to conflict with the pictorial information for a slanted surface. If the infants perceived the stimulus as a rectangular surface slanting in depth, they would be expected to reach for the pictorially "near" side. The 6-month-old infants reached more often to that side in the monocular condition, but not in the binocular condition. Infants of 5 months and younger reached equally to both sides under both conditions. Yonas, Cleaves, & Petterson (1978) concluded that 6-month-olds are sensitive to pictorial information for a three-dimensional layout, whereas 5-month-olds are not clearly so. They further concluded that when pictorial and stereoscopic depth information are placed in conflict, the latter wins.

These findings are consistent with the now large literature on pictorial depth perception in childhood. In brief, it has been found that children are sensitive to pictorial depth information, but they use this information less accurately than adults. Moreover, children's depth perception is facilitated by conditions that reduce information for two-dimensionality of the picture surface. For example, 3-year-olds appear to use linear perspective as information about the relative sizes of two objects in a picture if the objects pictured are three-dimensional and firmly planted on the surface (Benson & Yonas, 1973; Yonas & Hagen, 1973), but not if the objects are two-dimensional forms (Wilcox & Teghtsoonian, 1971), perhaps because such forms can appear to "float" above the perspective drawing (Benson & Yonas, 1973). Older children and adults use pictorial information for relative size in both cases. As another example, first graders, like adults, can use a texture gradient as information about the slant of a surface, but the accuracy of their judgments of slant increases with age (Degelman & Rosinski, 1976; Rosinski & Levine, 1976).

The above studies suggest that there are quantitative improvements with age in sensitivity to pictorial information for depth, particularly texture gradients and linear perspective. There may be qualitative changes as well, as the child becomes sensitive to new kinds of pictorial information for the relative distances of two objects. Children as young as 2 years have been shown to be sensitive to interposition in a distance-judgment task—an object was reported to be nearer than a second object when the first object occluded part of the second object in the picture (R. K. Olson, 1975; Olson & Boswell, 1976). Using reaching as a measure, Yonas & Granrud (1981) obtained evidence for sensitivity to interposition in 7-month-old infants as well. Young children are also sensitive to relative height in the picture plane as information for depth (Benson & Yonas, 1973; R. K. Olson, 1975; Olson & Boswell, 1976). But very young children do not consistently perceive the smaller of two objects as being farther away if all other information for depth is removed from the picture (R. K. Olson, 1975; Olson & Boswell, 1976; but see also Yonas & Granrud, 1981).

A second kind of change concerns the child's use of shading as information for the shape and depth of an object. Children as young as 3 years are sensitive to shading information when the pictured objects are lit from above and they are viewed in their normal orientation (Benson & Yonas, 1973; Yonas, Goldsmith, & Hallstrom, 1978). But young children can be misled by shading information if the direction of lighting is not the usual one and particularly if the direction of lighting in the picture differs from the direction of lighting in the testing room (Hagen, 1976; Yonas, Kuskowski, & Sternfels, 1979). In this respect, children may have difficulty perceiving a picture as independent of the surroundings in which it is viewed.

A third kind of change concerns the child's perception of suggested movement in pictures. Movement of an object in a picture may be conveyed in a variety of ways, but most fall into two categories. First, an object is perceived to be moving if it is depicted in an unstable position, for example, a person in a running posture with legs off the ground. Second, an object may be perceived to be moving if its motion is represented by cartoon conventions, such as lines or clouds of dust to represent vibrations or swift motion forward. Friedman and Stevenson (1975) presented children aged 4, 6, and 12 as well as adults with cartoon figures of a person whose movement was depicted posturally or conventionally. All the subjects were sensitive to the postural information for movement. Only the sixth graders and adults, however, were sensitive to the conventional information for movement.

A final developmental change is perhaps the most interesting. When adults view a picture at an oblique angle, the perspective information they receive is distorted. Yet, adults appear to perceive the pictured spatial array more or less as the artist intended it to be, not according to the oblique projection received from their less-than-optimal station point. Studies of the development of this ability have uncovered a complex pattern of change (Hagen, 1976; Hagen & Elliott, 1976; Hagen & Jones, 1978). In general, adults are better able to perceive the spatial properties of objects from an oblique view than are children, provided that the surface qualities of the picture are made obvious. Adults are better able to perceive from an oblique view if they can detect what the angular orientation of the picture plane is. For 4-year-old children, perception of the spatial properties of a pictured object is less accurate from an oblique view than from the "correct" station point. Hagen (1976) speculates that a mechanism compensating for an oblique view develops over the course of childhood.

Hagen's (1976) work underscores what she calls the special character of pictorial perception. On one hand, pictures incorporate information that also specifies the three-dimensionality of the normal spatial layout—the gradients of texture that are produced when one textured plane is projected from one point onto another plane. On the other hand, a picture presents a special kind of optic array that captures the properties of the layout only in a frozen moment of time, from a single point of observation and on a two-dimensional surface. To perceive the layout in a picture, one must attend to the scene that is depicted rather than to the picture as an object. To perceive movement in pictures, one must detect the instability of an object's position or follow certain artistic conventions. To perceive spatial relationships from an oblique station point, one must detect the invariant relation between one's own perspective and the artist's perspective. Even young infants can perceive objects in pictures and are sensitive to certain pictorial information for the layout. But perception seems to progress toward recognizing the special character of pictures, perceiving both their three-dimensionality and their two-dimensionality, both movement and stasis, and both the layout and a projection of the layout.

AFFORDANCES: PERCEIVING FOR SOME PURPOSE

Three Views

In our view, perception is intrinsically active, purposeful, and meaningful. Perception is active and purposive because it results from a search for invariance, be this the scanning of a newborn infant who follows a moving object or the systematic exploration of a biologist examining tissue under a microscope. Perception is inherently meaningful because we perceive the affordances of the world—the possibilities for action that are offered by the objects, events, and places that surround us. The gropings of a newborn are as actively oriented toward the discovery of possibilities for action as are the investigations of an adult.

The perception of affordances undoubtedly develops. As the child acquires new knowledge about the world and develops new capacities to act in it, her exploration becomes more diversified and her goals become more specific and explicit. As adults, we are often aware that we are perceiving for some purpose—to avoid the oncoming traffic, to locate our spectacles, to make out the handwriting of a student's midterm essay, to learn how to operate a new tool that someone is demonstrating. Yet, the perception of a 15-month-old trying to steer a spoon to her mouth seems equally purposeful, however incapable the child is of describing her purposes.

Many perceptual theories have denied that perception is inherently purposeful and oriented to action. To those who adopt the perspective of traditional learning theory, for example, perception is not guided by any intrinsic purpose at all. The goals of perception are provided by the environment through positive and negative reinforcement. Thus, perception is itself a passive process, one devoid of intrinsic meaning and incapable, in itself, of bringing knowledge. From this view, we do not perceive affordances but merely learn to respond in certain ways to certain patterns of stimulation. What appears to be the perception of meaning is really the association of responses to meaningless patterns of sensation.

For those who view perception from the perspective of information-processing theory as well, perception is passive and devoid of meaning. An information-processing theorist would contend that the goals of perception are not intrinsic to perception but are provided by cognitive representations and the relations that those representations express. From this view, affordances are not perceived; knowledge of affordances results from the interpretation, or categorization, of sensory information through operations on mental representations. These representations and operations are also sometimes conceived to be associative in nature.

These three perspectives differ in their accounts of how new affordances are learned. A traditional learning theorist would contend that this development depends on the acquisition of new forms of behavior through reinforcement; an information processing theorist would contend that this development depends on the construction of new mental representations, or categories, again perhaps by association. We suggest that this development depends on the search for, and detection of, new invariants and transformations in arrays of stimulation.

Affordances and Action

Exploration aimed at the discovery of new affordances would seem to begin in earliest infancy (see *Exploring and Attending*). From the beginning of life, infants tend to look and listen to objects with the most important affordances. For example, the voice of the mother is selectively attended to in a field of noise (Benson, 1978), and infants will act to make it available if possible (DeCasper & Fifer, 1980). As children grow, however, they make greater and greater efforts to discover new affordances through active exploration.

This exploration becomes very pronounced in the second year of life, as was described vividly by Piaget (1952). Piaget noted that his children, beginning at about 12 months of age, began to act on the world systematically in new ways to observe the consequences of those actions. For example, he describes how Jacqueline, in her bath:

> engages in many experiments with celluloid toys floating on the water. At 1,1 (20) and the days following, not only does she drop her toys from a height to see the water splash or displace them with her hand in order to make them swim, but she pushes them half way down in order to see them rise to the surface. (Piaget, 1952, p. 273)

It seems very likely that children discover many of the basic affordances of the world through such experimentation.

Active experimentation also brings the child information about tools. Piaget (1952, pp. 279 ff.) has described how a child learns to use a string that is attached to an object as a means to bring the desired object within reach. At first, the child reaches for the object directly, ignoring the string. At other times, he may pull the string but without noticing the systematic effect of this action on the location of the object. Finally, the child grasps the relation between the position of the string and the position of the object. In the future, the string will serve as an instrument that can be used to retrieve that object (see also H. M. Richardson, 1932). In these cases, the child does not appear to learn through random trial and error. He actively searches for information about the invariant relationships between objects and the affordances for action that they provide.

If the instrument in question is more specialized, the process of discovering its affordances is more involved. Koslowski and Bruner (1972) examined in detail the strategies employed by children learning to use a rotating lazy Susan lever to bring a toy into reach (see also Piaget, 1952, p. 284; H. M. Richardson, 1934). The children were between 12 and 24 months of age. A bar rested on a rotatable circular platform, the whole mounted on a table beside which the child was placed. A toy was secured to one end of the bar, directly opposite the child, but out of reach. At first the children maneuvered directly along the line of sight of the toy, reaching for it, then pushing or pulling on the lever. The next step was discovery of rotation: the bar was simply oscillated back and forth, an interesting affordance of its own. If the child was somehow distracted from operation of the lever and caught sight of the goal, he reached for it if it was nearby. It was necessary to focus on rotating the lever, to the momentary exclusion of the goal, and then to detect the goal's position. Finally the child discovered the lever/goal relation. Discovery of this affordance depended on perception of a relationship between two events, the rotation of the lever and the movement of the object. Moreover, each event had to be perceived in relation to the child's actions of turning the lever and of reaching for the goal object. Once this relationship was detected, it was highly generalizable—an affordance had been discovered for a kind of tool.

As children grow, they perceive the affordances of more and more tools as they discover the relationship between a tool and the consequences that it can produce. A child of 5 knows, for example, that the slicing of an apple can be accomplished with a knife and the cutting of paper accomplished with scissors (Gelman et al., 1980). These discoveries appear to come about as the child acts on objects with other objects, perceiving both the transformations that his actions bring and the properties of objects that they leave invariant.

In all of the above examples, children discover the affordances of objects as they act on them directly. But children also discover affordances by observing objects being transformed by others. As studies of observational learning reveal, children are often attentive to the actions of other people on objects, and they are apt to repeat those actions (see Stevenson, 1970, for a review). We think that they do so because the actions of others provide information about the affordances of the world. An experiment by Bandura and Menlove (1968) illustrates change in the perceived affordance of a class of objects through observation. A group of children who were markedly fearful of dogs was shown a series of films in which models interacted nonanxiously with dogs of varying size and fearsomeness. Significant reductions in the children's avoidance behavior resulted.

In summary, the perceived affordances of objects change with experience. As the child observes objects participating in events and as he acts on those objects himself, he discovers more and more of their possibilities for action. We believe that this learning brings a change in the child's perception of those objects, not merely a change in the child's responses to certain stimuli as a traditional learning theorist might contend. A theory of response learning by association fails to account for the active nature of exploration in the cases we have described. It also overlooks the information in stimulation, the invariant relationships that can specify an affordance and lead to perceiving the object in a new relation to other things and to the perceiver. Information about these relations specifies the object's affordance and is abstracted from all other information about it. The extraction of new information specifying an affordance usually has two interrelated consequences: (1) differentiation of the object from otherwise similar objects lacking the affordance and (2) perception of correspondences between different objects with the same affordance. We now consider these two kinds of change.

Affordances and Differentiation

When a child or an adult explores the distinctive affordances of a set of very similar objects, he learns to differentiate among those objects. The fledgling bird watcher learns to differentiate between a nuthatch and a chickadee; the novice little leaguer learns to distinguish a fast ball from a slider; the apprentice carpenter learns to discriminate walnut veneer from mahogany. Studies of differentiation are now legion, and have been discussed in detail (E. J. Gibson, 1969). Unfortunately, these studies were rarely carried out with real objects and events—the kinds of things that we most often learn to differentiate in the natural world. It may be that it is difficult to specify what the basis for differentiation could be in an interesting and internally confusable set of natural objects: What is the information by which we identify a chickadee? A human face? Nevertheless, real objects and events appear to be the first things that children differentiate.

Other people are objects with particularly varied and important affordances for infants, and infants begin to differentiate them at birth. Research on the development of perception of human faces was described earlier. It is notable that the earliest distinction made seems to be between faces and nonfaces. The usual misleads presented have been bizarre arrangements of facial structure. As we pointed out, this research does not reveal how one face is distinguished from another, nor do we know exactly how adults recognize faces. It seems likely, however, that we recognize particular faces by detecting certain invariant relationships in the face, in particular its unique configuration of features (Carey, 1978). Sensitivity to these invariants may develop rather slowly. The research to date suggests that whereas children do recognize particular people at an early age, they do so by relying more than adults do on superficial characteristics (e.g., a hairstyle), at least when they are given only momentary static information, such as a photograph. But it remains possible that infants would abstract invariant properties of a face if they observed a person in action.

One recent study has been taken to suggest that infants do not analyze component features of faces at all. Fagan and Singer (1979) presented infants 5 to 6 months old with photographs of babies or adults of either sex who were similar or dissimilar in some gross features, such as hair (bald vs. full heads of hair), face shape (round or oval), eyebrows (prominent or not), and so on. The photographs were selected so that pairs of faces disparate in age or sex were judged as having fewer feature differences than pairs of same sex or age. The method was familiarization followed by a preference test. Faces judged as similar in many features but different in age or sex were easily discriminated by the infants, but pairs of like-sex, like-age faces with features rated very dissimilar were not distinguished. This finding seems to rule out feature analysis as the basis of the infants' discrimination of faces, but only on the assumption that the experimenter manipulated the right set of features. A possible difficulty may be that features were judged as absolute, whereas the information that distinguishes one face from another is relational. For example, features like eyebrows are embedded in a larger facial structure. Because the larger structure appears to be differentiated first, it seems likely that the embedded structures would be segregated, whenever they are, in relation to the larger structure rather than as isolated components. Indeed, if infants were not sensitive to some relational structure, it is hard to see how they could differentiate between faces of differing ages and sex.

A wealth of research on discrimination of alphanumeric characters and forms suggests that children of school age become increasingly sensitive to contrastive relations in this domain (see Gibson & Levin, 1975, for a review). How does such skill improve? An experiment by A. D. Pick (1965) sought to compare two hypotheses. According to the schema hypothesis, sensory input about objects is matched to a representation of the object that has been built through repeated experience and is stored in memory. Improvement in discriminating or identifying objects would occur as new schemes are constructed. According to the differentiation hypothesis, subjects learn the contrastive relations that serve to distinguish among the items. Improvement consists of discovering the transformations by which the members of the set are distinguished from one another. A. D. Pick's experiment utilized letterlike forms to be discriminated by kindergarten children. A training session with a set of standard forms and three transformations of each of them was followed by one of three transfer conditions. In one (a base condition) a new set of standards and three new transformations of them were presented for discrimination. In a second, the original standards were presented along with new transformations of each of them. In a third, there were new standards, but the same transformations for each of them were presented. Both conditions two and three yielded positive transfer compared to the base condition, but group three (retaining the transformations already learned about) showed most facilitation. A. D. Pick carried out further experiments with comparable forms and transformations adapted for tactual discrimination. When the subject felt the forms to be discriminated successively, conditions two and three were both superior to the base condition but did not differ from one another. In another experiment, tactual discrimination was carried out simultaneously, one form being explored by each hand. In this case, only condition three (same transformations retained) was facilitated. Differentiation depended in large part on the discovery of the transformations defining critical contrastive relations within the set of forms.

A large number of experiments on learning to discriminate letterlike forms and real letters have been performed since A. D. Pick's experiment, many of them providing training in the discovery of contrastive relationships (e.g., Samuels, 1973). Comparisons of such training with other methods of learning to discriminate and identify forms have often been made. Silver and Rollins (1973), for example, compared acquisition and transfer of letterlike forms following both visual and verbal emphasis on contrastive relations, visual or verbal emphasis alone, or observation of the forms without such emphasis. Visual emphasis of the distinctions among forms was most effective. Zelniker and Oppenheimer (1973, 1976) compared several methods of training impulsive children to discriminate letterlike forms. Training in differentiating transformations was more effective than training in matching identical forms.

Because the objects presented in these tasks were created by the experimenter and depended necessarily on the transformations that were built into the material, the results may not capture the course of perceptual differentiation of natural objects. It does seem appropriate to conclude, however, that in tasks where distinctions must be made, children come increasingly to attend to the relevant contrastive relationships among objects. As they attend to more and more of these relationships, perception becomes increasingly differentiated. Moreover, it seems to us that this differentiation is brought about through the child's efforts to distinguish objects with different affordances. The affordances of the material used in these tasks are far removed from the affordances of a human face, a hammer, or a baseball pitch. Nevertheless, perception becomes differentiated in all these cases because each object has distinctive affordances within the context of the task. A child of school age knows that alphabetic characters have affordances—they mark the crucial distinctions between one word and another in written language. The child becomes able to act on the affordances as he differentiates between letters by detecting the invariant relationships that distinguish them.

Affordances and Categorization

Discriminably different objects may have the same affordances. A cup, a glass, and a jar all afford containment of water and drinking—emptying their contents into the mouth. The characters t, T, and *t* all afford distinguishing the word *table* from *cable* or *fable*. When a child is engaged in a task and is oriented toward the discovery of the relevant affordances for that task, she will focus on those invariant properties of all containers or all Ts that specify their common affordance. It could be said that she treats all those different objects equivalently and that all of them form a category for her.

One of the clearest cases of perceptual equivalence arises in the domain of speech perception. Phonemic distinctions are made categorically along many of the acoustic dimensions on which speech gestures differ, such as voice-onset-time and place of articulation. Stimulus samples ranging along a physical continuum, such as voice-onset-time, are identified over a considerable range as corresponding to a single articulatory gesture. Moreover, discrimination among them seems to be poor, at least in certain tasks. The end of this range appears to constitute a sharp boundary, partitioning off another distinct category when it is crossed; discrimination at this boundary is high. Categorical perception of speech was first noted with adult subjects (Liberman, Harris, Kinney, & Lane, 1961; Lisker & Abramson, 1970) and led to the notion that there was a special, learned mode for perceiving speech.

About 10 years after the original discovery, the role of learning came to be questioned. Experiments by Eimas et al. (1971) indicated that categorical perception of speech gestures differing in voice-onset-time was present in very young human infants. Experiments on infants' categorical perception of phonemic distinctions now abound (see Aslin & Pisoni, 1980; Eimas, 1975; Jusczyk, 1979; Strange & Jenkins, 1978, for recent summaries). There is evidence, however, that infants born into one language group perceive certain phonemic distinctions categorically even though their parents do not, that is, despite the lack of a categorical distinction in the language they are hearing. Nature seems to have provided for sensitivity to all the contrasts that different languages embody, but learning is presumably responsible for the increasing correspondence between phonemic perception and the phonological structure of a given language.

Many species of animals, insects as well as vertebrates, have evolved auditory systems that are selectively attuned to those classes of acoustic information that have utility for them, particularly information specifying gestures of other conspecifics (Marler, 1970). A nice example of this selectivity is the sensitivity to predator alarm calls in vervet monkeys. Adult monkeys give alarm calls for predators that are specific to different classes of predators and elicit appropriate defensive behavior (e.g., snake alarms elicit looking to the ground, whereas eagle alarms elicit looking up and running into dense bush). Infants respond to these alarm calls, but their responses are generalized to nonpredators and are not sharply differentiated. Even for infants, however, alarm calls are differentiated according to relatively general predator classes in relation to appropriate behavior. Further differentiation of affordances of species within a class develops with experience (Seyfarth, Cheney, & Marler, 1980).

Human infants and adults are said to perceive speech categorically. What does this mean? Cognitive theorists have provided two different accounts of categorization. Some have proposed that the child detects certain discrete attributes of an item (in this case, an utterance) and categorizes the item in accordance with a rule specifying those attributes all items in a particular category have in common. Others have proposed that the child has a representation of an ideal example, or prototype, corresponding to each category and that he categorizes incoming items in terms of their similarity to each of the prototypes. But neither of these accounts seems very plausible when applied to speech perception in infancy. A third view proposes that the child performs no special act of categorization but rather detects certain dynamic invariant relations in the acoustic waveform—relations that correspond to phonemic distinctions based on articulatory gestures of a speaker (Bailey & Summerfield, 1980). These invariants are abstract and potentially intermodal (MacDonald & McGurk, 1978).

Each of these views provides a different general account of the categorization of natural objects. The view that all categorization depends on a rule defined over a set of attributes has been predominant in psychology and has played a major role in philosophy and linguistics as well. To study the development of categorization, psychologists have generally made use of highly artificial material, such as combinations of forms and colors or schematic line drawings of faces with fixed numbers of attributes combined by a rule arbitrarily imposed by the experimenter. The subject is forced to abstract a rule to describe a class of items, each of which is obliged to possess the defining attributes. But we doubt that the natural concepts of infants or children are abstractions from a few dimensions. By 28 or 30 weeks, infants can categorize photographs of real faces as those of a man or woman (Cohen & Strauss, 1979; Cornell, 1974; Fagan, 1976) and real voices as those of a man or woman (Miller, Younger, & Morse, 1980). In these cases, it seems unlikely that the infants are constructing a class on the basis of a few discrete attributes shared by every token. The experimenters themselves could define no such combination over the variety of exemplars they provided.

As has been noted many times, it is hard to define any natural concept completely in terms of a set of physical attributes. In light of this difficulty, it has been argued that natural categories do not have sharply defined boundaries nor a logical definition that presupposes a small set of discrete attributes or components shared by all members. Instead, categories in nature are organized around a prototype or best example to which other members of the category are related to a greater or lesser degree (Rosch, 1973a, 1973b; Rosch & Mervis, 1975; Wittgenstein, 1953).

Rosch's work began with categorization of colors and forms, but she subsequently focused on categories of natural objects that share clear affordances, for example, furniture, tools, and vehicles. Unfortunately, it is difficult to describe such categories in terms of a prototype and members that are globally similar to it. A car may be a prototypical vehicle, but a toy car—which is not a vehicle at all and lacks its principal affordance—is featurally more similar to the prototype than is another genuine vehicle, such as a sailboat. In view of such problems, Rosch and Mervis (1975) described the prototypes of these categories not in terms of global similarity, but in terms of features—mostly physical attributes—and they rooted the process of categorization in the analysis of features and the applications of rules, much as do the psychologists whose view of concepts Rosch opposes. Thus, many of the problems of the older approach remain.

A different view of concepts and categories emerges if one acknowledges that perception is always abstract and meaningful and that normal perception always depends on the detection of invariance over change. From this view, the acquisition of a concept depends on the extraction of invariance over transforming events. For example, consider a particular kind of affordance, that of rigidity of substance. A rigid object in motion is differentiated, whatever its trajectory, from an object changing its form (Johansson, von Hofsten, & Jansson, 1980). As we have noted, invariant information for rigidity of substance is differentiated from elasticity of substance in infants as early as 3 months (see *Obtaining Information About Objects*). The objects used in these experiments (E. J. Gibson et al., 1978; E. J. Gibson et al., 1979) were identical in all their static properties; no static presentation of the object ever occurred. Therefore, the information for rigidity versus elasticity had to be the invariant provided by the contrasting types of motion. Whether one calls the perception of rigidity over perspective transformations a concept depends on what one thinks a concept is. If one believes (as we do not) that perception is concrete and conception is abstract and that to have a concept is to apply an abstract rule to a set of concrete exemplars, then these experiments say nothing about the concept of rigidity. The infants in these experiments cannot be storing a set of discrete, frozen images of an object, applying some rule to each image, and abstracting a category. They are detecting invariance and change in a continuous stimulus flow. The end product of their activity is not, we think, the construction of a category representation in the mind, but the perception of an affordance of the world.

As a second example, consider a very different set of concepts, concepts of number. The number of objects or events in a collection contributes greatly to the affordances of that collection—affordances for action often depend on the number of pennies in one's hand or the number of times one has been caught speeding on the highway. It is now clear that young infants are sensitive to the number of objects in a display or the number of events in a sequence, provided that the total number is small. For example, Starkey et al. (1980) presented 6- to 8-month-old infants with a series of photographic slides of arrays of natural objects (see also Strauss & Curtis, 1981). For infants in one group, every slide in the series contained two objects; for the infants in the other group, every slide contained three objects. The particular objects within each slide were heterogeneous—they varied in color, shape, and size. Moreover, the objects changed from one slide to the next, and their configuration changed as well (in slides of three objects, the objects could form any of a large set of differently shaped triangles or differently oriented lines). The infants in both groups were habituated to the slides in these series. After habituation, they looked hardly at all at slides of new objects in new configurations if the number of objects remained the same. When a display containing a different number of objects was presented, infants looked with renewed attention. It seems, therefore, that infants can detect a very abstract invariant property—the number of objects in a display—over changes in the particular objects and their configurations. Subsequent studies (Starkey, Spelke, & Gelman, 1982) revealed that infants 6 to 8 months old can detect a numerical invariance over even greater changes—they detect a correspondence between the number of visible objects in a spatial layout and the number of audible beats in a temporal sequence.

There is, of course, more to the human conception of number than these experiments reveal. For an adult, numbers form an ordered series; it is not clear if this is so for infants. Moreover, adults appreciate that different numbers are related by transformations of addition and subtraction. Preschool children appear to know this as well (Gelman, 1972), but it is not certain whether infants do. It seems likely, as Gelman speculates, that the operations of addition and subtraction come to be understood by children as they witness the application of those transformations to actual collections, observing the reversible nature of the transformations and discovering their effects on the number of objects in the collections. Conceptions of number also appear to develop as the child acts on collections of objects to produce a very important reversible event, counting (Gelman & Gallistel, 1978).

Whether or not one considers the abstraction of number as a perceptual or a conceptual achievement depends, once again, on what one means by these terms. Yet, number concepts illustrate the continuity of perception and cognition. Like concepts of substance, number cannot easily be viewed as the application of a rule to concrete physical attributes: What are the attributes of *three*? Neither is number easily viewed as organized around a prototype (see Armstrong, Gleitman, & Gleitman, in press). Instead, it seems that number is an abstract property of a set of objects or events that is invariant over a particular set of transformations. Number is abstracted over changes in the color, size, or spatial configuration of objects. Specific numbers are distinguished from each other by other transformations—addition and subtraction. Children appear to come to understand number as they observe these transformations and discover both the changes they bring and the properties they leave unchanged.

From our view, there is no firm line to be drawn between perception and cognition as the child gains knowledge of the affordances of the world—affordances that eventually are given conceptual descriptions, such as rigid, square, animal, or three. Knowledge of all these properties depends on the detection of invariance over change. As the child grows, he will discover things about substance, form, animacy, and number that he cannot perceive, discoveries that are formalized in science and mathematics. These discoveries may depend on innate and developing structures that are not related in a direct way to the child's perceptual systems. But the underlying continuity between perception and conception remains. Both perception and conception are abstract and meaningful. Both depend on the detection of invariance and are directed to the discovery of affordances. Both perceptual and conceptual knowledge are always less specific than the infinitely dense and variable world that is there to be known. Meaningful groupings of objects and events in the world inevitably result from the very nature of perception itself. No special act of categorization need be postulated to explain them.

It would be a mistake to think that information in the world is so random, unordered, piecemeal, and unrelated that economy of perception could only be achieved by forming categories on the basis of arbitrary and accidental combinations of recurring elements. Order and invariance exist in nature. Perception shows a trend toward economy by abstracting from changing temporal contexts the order that exists.

Overview

We have suggested that perception is inherently purposeful. It results from an active search for invariants in stimulation, and it is oriented toward the discovery of the affordances of the world. This search leads to the differentiation of perception through the discovery of new contrastive relations between objects, a way of learning about the world (E. J. Gibson, 1969). It also leads to the discovery of affordances that different objects share, properties like rigidity and animacy.

Our view contrasts sharply with the approach of traditional learning theories to purpose and meaning in perception. Perception and action are interleaved, and the relation between them cannot easily be explained in terms of association and extrinsic reinforcement. Actions, both exploratory and performatory, reveal new affordances, and perception of new affordances makes possible new actions.

Our view also contrasts with the approach of information processing theories. Perception and cognition are interrelated, but perception does not depend on cognitive processes by which representations of meaningless sensory impressions are categorized and given meaning. Perception depends on the detection of invariance and change. The development of many concepts may depend, in turn, on detecting these invariant relationships.

Perception is an autonomous, developing domain of competence. It depends, for its development, on its own intrinsic processes of exploring, detecting invariance, and perceiving affordances.

THE COURSE OF PERCEPTUAL DEVELOPMENT: A SUMMING UP

To perceive is to monitor the environment and what happens in it in the service of guiding one's behavior. Perception depends on obtaining information about the environment from an array of potential stimulation. We have stressed three concepts

in describing this process—exploration, discovery, and differentiation, and we have stressed the reciprocity between the animal and the environment through the concept of affordance.

Obtaining knowledge of the environment begins with exploring it. Different species of animals are endowed with different means of doing so. Some precocial animals seem to be extraordinarily ready to act on the perceived affordances of events such as the retreat of the mother; of places such as a surface that is safe for locomotion; and of things such as a grain that is edible. Humans are not a precocial species, but the means for exploring the events, objects, and layout of the world are adequate at birth to begin the long process of gaining knowledge about the surrounding environment and themselves in it. Means of exploring develop and become more skillful for many years—extending even into an adult's professional life when exploration with tools like telescopes and stethoscopes may be required—but the competence of the perceptual systems is impressive even in neonates.

Exploration results in the discovery of persisting aspects of the layout like ground, sky, and walls; of events like things approaching and things going away; and of properties of objects like their shape and substance. All of these have affordances for behavior, some of them probably perceived immediately as the infant actively explores by sucking and looking.

The third concept, differentiation, refers particularly to development (E. J. Gibson, 1969). Perceptual learning seems most appropriately thought of as a process of differentiation, of perceiving progressively more deeply embedded structure and more encompassing superordinate invariant relations. Progressive differentiation of structure is particularly obvious as children learn language or music. But it is also apparent in perceiving other events such as games, and in developing recognition of faces and objects such as toys and tools, although the latter have been little studied. The literature on developing perception of places seems especially well interpreted as a process of differentiation. Features of places, such as doorways, barriers, and dropoffs, are differentiated early (Carroll & Gibson, 1981; Walk & Gibson, 1961), but paths through a large space and places where things get lost are differentiated later as more far-ranging behavior needs guidance.

Perception of affordances develops along with differentiation of objects, places, and events; it is their affordances that are perceived. A toy may at first afford only grasping, later chewing, later rolling along the floor, still later taking apart, and finally fitting into a large construction of blocks, like a parking lot or a garage. A pair of pliers for a 12-month-old infant usually has the affordance of an object for banging and noise making. For the average adult, it has the affordance of a useful tool. Its affordance as a tool for a new purpose, such as weighting a pendulum, is not always apparent even to the adult, but it can be made to be if the adult looks at the pliers with a new requirement.

What kind of changes and continuities stand out in the course of development? We have found no indication of stages in perceptual development; continuity seems to be far more apparent than abrupt change. Five kinds of change are worthy of comment. First, there are changes in the selective, purposeful aspect of perception. Traditional theories have usually implied that perception is initially inflexible, unguided, and nonselective, but here is a case where continuity, as we look at the research of recent years, is remarkable. Exploration of the world appears to be directed and selective, to some extent at least, from the start. Selecting one event to follow, when more than one is going on, is a particularly striking case (Bahrick et al., 1981; Spelke, 1976). Nevertheless, perception comes to serve a greater range of purposes with development. Exploration becomes more systematic and makes more use of order in events and in the available information. Tasks become more specific as goals diversify and as other people's requirements constrain patterns of exploration (Gibson & Rader, 1979).

Second, awareness of affordances increases as children grow. We do not endorse the traditional view that perceptual development proceeds from the meaningless to the meaningful, from sensation to knowledge. Nevertheless, it is clear that children come to perceive new affordances of the world as they explore it. Again, development is continuous: the child discovers new affordances of a world that already has affordances for action.

Third, as differentiation occurs, perception increases in specificity (E. J. Gibson, 1969). Diversity and detail, fine structure, invariant relations and affordances of a greater subtlety are detected. At the same time, higher order structure is differentiated. But along with this increase in sensitivity to information about the world goes a fourth trend toward increasing economy. Perceiving becomes more efficient as exploratory skills increase and as the critical, minimal information for guiding action is detected. This change has often been noted in the past (E. J. Gibson, 1969) and research in recent years confirms it. There is continuity even here, for the youngest infant appears to search for invariants—the information for persisting structure over the maelstrom of change. As this search becomes successful, what is picked up is more and more what is sufficient for the task in hand. Guidance of skillful performance of motor tasks, like catching a moving object, is a nice case. At 4½ months, an infant aims predictively (von Hofsten, 1979, 1980), but guided movements later become fewer and more ballistic. An outfielder in a baseball game is so efficient at picking up the information for where the ball will be that it appears magical to the unskilled. Eye movements of comparison become more efficient in children as contrastive relations are detected. These cases show the interplay between perceiving and exploring.

The fifth change is the increasing generalizability of perceived affordances of things and places to new situations and to newly developing action systems. In early perceptual development, perceiving an affordance of an object for action may be effective only as a guide to limited actions in certain narrow contexts. Properties of things that have been detected through actions or through observations of events may be perceived, but often a child is slow to detect their utility when a different kind of action is required or a quite new task arises. Increasing ability to relate perceived affordances of things to new task demands and to different actions may be a key factor in perceptual development.

Metacognition has become a popular concept in developmental psychology (see Brown, Bransford, Ferrara & Campione, Vol. III, Chap. 2; Flavell, 1978). Do children become more aware of what they perceive and of the invariants that specify things in the world? This is an interesting question, and it is possible that developing awareness can hasten perceptual differentiation. But it is clear that a perceiver need not reflect on the properties of the world to perceive them. To perceive the world is not to describe it to oneself. It is to extract information about its affordances, information that keeps an active animal in touch with the world around it.

NOTES

1. This position was developed most clearly by Helmholtz, Wundt, and Titchener. An early opponent was Mach. See Johansson, 1978, and Johansson, von Hofsten, and Jansson, 1980, for a discussion of these opposing positions.

2. One should be wary of concluding that discrimination was impossible for the 4-month-old infants because negative evidence does not guarantee lack of competence, especially in the absence of a no-change control group. This danger has often been remarked by researchers who work with animals and preverbal children (Gibson & Olum, 1960; Kagan, Linn, Mount, & Reznick, 1979).

3. There are other, noneuclidean metric geometries that also preserve distance, angle, and all projective and topological properties. We do not discuss them here.

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LEARNING, REMEMBERING, AND UNDERSTANDING* — 2

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CHAPTER CONTENTS

INTRODUCTION

Scope of Chapter

It seems somewhat perverse to begin a chapter, particularly one of this length, with details of what will not be included. But the title of learning, remembering, and understanding affords such an open-ended task that we felt it necessary to limit quite stringently the boundaries of the domain we would cover. Given the length of the chapter, some might question whether we were stringent enough!

In the section of the previous Handbook devoted to cognitive development (Mussen, 1970), there were two chapters on learning, one on reasoning and thinking, and one on concept development—but

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